KAOLIN OF INDIANA

By W. N. LOGAN, State Geologist

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Chapter I.

INTRODUCTION.

The deposits of kaolin in southern Indiana have long attracted the attention of the scientist. The occurrence of deposits of kaolin of extraordinary purity and crystalline appearance apparently interstratified with sedimentary rocks was to him an extremely unusual phenomenon.

Less frequently has the attention of the manufacturer been attracted by the commercial possibilities presented through its utilization. Since the discovery in 1874 of a thick bed of kaolin on the property long owned by the late Dr. Joseph Gardner in Lawrence County the kaolin from this deposit has been used intermittently.

In the autumn of 1916 the writer began investigations with a view to determining the origin and of extending the utilization of the kaolin. One line of investigation led to the testing of trial mixtures of kaolin and Indiana fire clays for the possible manufacture of refractories. The other line of investigation concerned itself chiefly with a study of the origin of the kaolin. The results of these and other lines of investigations are embodied in this report.

Following the entrance of the United States into the European war, the demand for kaolin suitable for the manufacture of glass pots, white ware, refractories and for purposes connected with chemical warfare became very insistent, for the reason that the European supplies were no longer available because of transoceanic transportation difficulties.

Upon request, the writer secured and made shipments of Indiana kaolin to several ordnance laboratories and to the Bureau of Standards. Shipments of many cars of kaolin were made also from the Gardner mines. This kaolin was used near St. Louis, Mo., in the manufacture of a refractory material called "Malinite."

At the request of Professor H. Reis, who had the investigation of clays and kaolins in charge for the United States Geological Survey, the writer prepared a brief report on the kaolin of Indiana. This report was published in Bulletin No. —.*

* Now in press.

The report contains a brief discussion of the geological occurrence, the origin and the geographical distribution of the kaolin.

The kaolin of southern Indiana was first mentioned in the geological literature by Leo Lesquereux[1] who suggests that it is a very soft ochrous clay which has resulted from a burning out of a bed of coal. This deposit is near Dover Hill in Martin County.

The occurrence of the white kaolin in Lawrence County is first referred to by E. T. Cox[4] as follows: "One of the most interesting as well as valuable discoveries made during the year is a large bed of White Porcelain Clay in the Carboniferous rocks of Lawrence County." He says that the bed, stratified with the rocks, is from five to six feet thick and may be traced over a large area of land.

"The principal body of clay is on section 21, town 4, range 3. This property has been purchased by Dr. J. Gardner of Bedford, Lawrence County, who has associated with him Messrs. Tempest, Brockman and Co., the pioneer potters of Cincinnati. This firm has given the clay a thorough practical test and finds that it makes a beautiful white ware equal to the best English iron-stone china."

To the kaolin Cox applied the name "Indianaite" and gave a discussion of its origin, which he assigned to the decomposition of a bed of limestone.

Maurice Thompson[5] discusses the mode of origin suggested by Cox and asserts that a large part of the silica composing the kaolin must have been contained in the clay. He thinks the silica was derived from the sandstone by the leaching action of meteoric waters.

W. H. Thompson[6] supports the view of Maurice Thompson and cites examples of the deposition of silica carried in solution by meteoric water.

Geo. H. Ashley[3] called attention to the fact that Lesquereux's view of origin has been overlooked and expresses his belief that the latter has hit upon the proper solution to the problem.

W. S. Blatchley[22] says in concluding a discussion of the origin: "While the facts at hand are not sufficient to fully justify either of the conclusions above given as to the origin of the kaolin, that of Lesquereux and Ashley is by far the more

plausible. It at least accounts, according to the laws of chemistry, for the presence of the silica and alumina which, with the combined water, made up 98.61 per cent. of the deposit."

ACKNOWLEDGMENTS.

The writer desires to acknowledge his indebtedness to the authors of the publications named in the bibliography accompanying this report; to Professor E. R. Cumings who assisted in the microphotographic work and gave many helpful suggestions during the progress of the investigations; to Professor R. E. Lyons for assistance in the chemical investigations; to Professor E. O. Jordan for assistance in the bacterial investigations; to Professor J. A. Badertsher who assisted in securing microphotographs of the bacteria; to Dr. C. A. Malott and other members of the field party of 1919; to Mr. Jacob Papish and Mr. C. C. Beals for field assistance; to Mr. P. B. Stockdale for assistance in the field and in the photographic work; to Mr. J. R. Reeves for assistance in the field and in the preparation of the drawings; to Mr. Willis Richardson and Mr. Howard Legge for assistance in the laboratory; and to Miss Alice O'Connor for stenographic work.

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[23] W. S. Blatchley, 31st Ann. Report. Geol. Sur. Ind. 1906, pp. 42, 43.

Chapter II.

THE PHYSICAL AND CHEMICAL PROPERTIES OF INDIANA KAOLIN.

Definition. The term kaolin is applied by Dana to a rock made up of one or more minerals included in the following group:

KAOLIN MINERALS.

	Silica.	Alumina.	Water.
Kaolinite, $H_4Al_2Si_2O_9$)	46.05	39.50	14.00
Meerschaluminite, $2HAl(SiO_4) + aq$	43.15	41.07	15.78
Halloysite, $H_4Al_2(Si_2O_9) + aq$	43.50	36.90	19.60
Newtonite, $H_3Al_2(Si_2O_{11}) + aq$	38.50	32.70	28.80
Cimolite, $H_6Al_4(SiO_3)_9 + aq$	63.40	23.90	12.70
Pyrophyllite, $H_2Al_2(SiO_3)_4$	66.70	28.30	5.00
Allophane, $Al_2(SiO_8)5H_2O$	23.80	40.50	35.70
Collyrite, $Al_4(SiO_8)9H_2O$	14.10	47.80	38.00
Schrötterite, $Al_4(SiO_8)30H_2O$	11.70	53.10	35.20
Gibbsite, $Al_2O_3, 3H_2O$		65.40	34.60

Since the Indiana white procelain-like material seemed to differ from other kaolins, E. T. Cox named it Indianaite. Because of its nearness in chemical composition to halloysite, Dana assigned it as a variety of that mineral species. It is essentially an hydrous aluminium silicate, containing in some places a bluish mineral of the approximate composition of allophane, and so called. The term which is applied to the Indianaite locally is kaolin. Some mineralogists would limit the term kaolin to residual deposits formed from the decomposition of feldspathic rocks. Under such restrictions Indianaite would not be a kaolin nor could it be called a sedimentary kaolin to distinguish it from the residual type, since it is partly of the nature of a replacement mineral, and partly of organic origin. Only a very small portion has been redeposited. The term kaolin as used by Dana, includes such minerals as kaolinite, gibbsite, halloysite, and others, and so the term may be properly applied to Indianaite.

Macroscopic Appearance.—The purest form of the kaolin is a white substance of porcelain-like appearance. When first taken from the deposit it often exhibits a pale sea-green color and is semi-translucent. After exposure to the air, it loses its green color and becomes opaque-white. The change is prob-

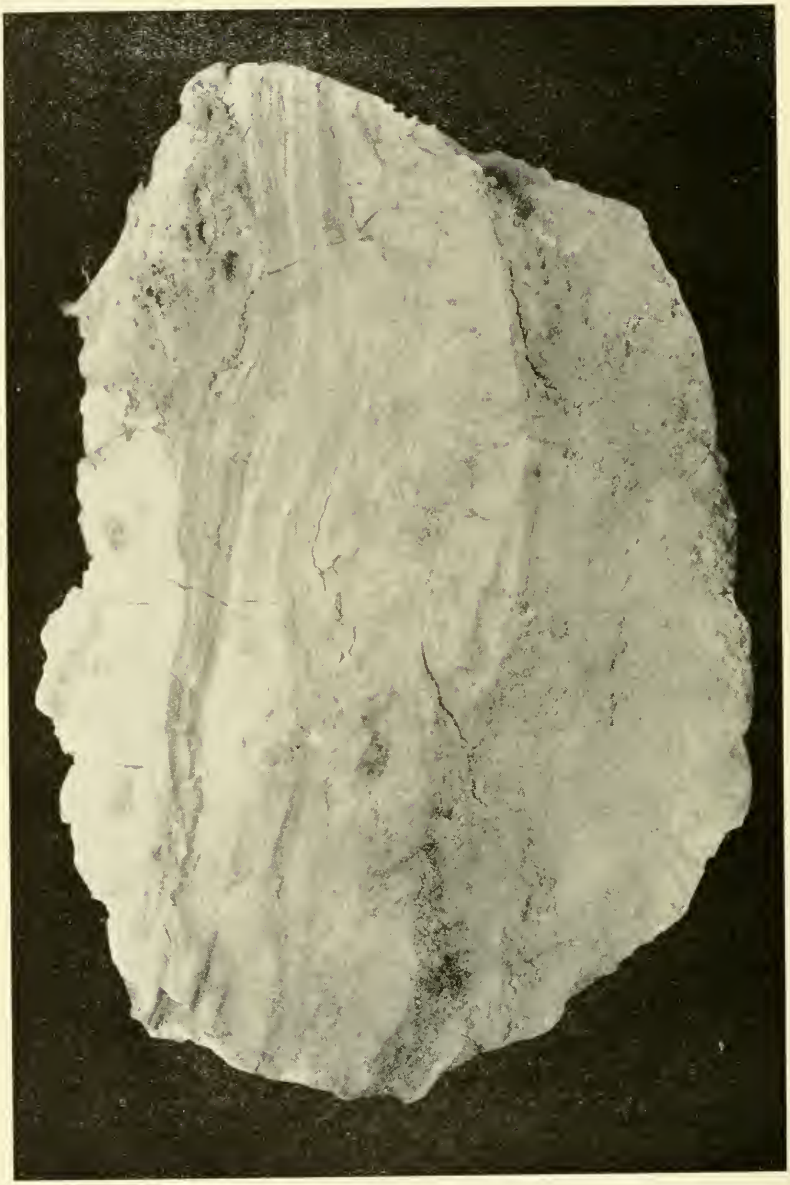

Plate I. Stained kaolin from the Gardner mine. Colors, white, yellow, purple and red.

ably due to loss of water. The larger masses of the kaolin when exposed to the air break up into small irregular fragments. These fragments do not pass readily into clay. Even when reduced to a fine powder, the kaolin remains non-plastic.

Porosity.—The white kaolin is porous, and when dry contains much air. When the kaolin is placed in water the air escapes rapidly from the pores, producing a sound like that accompanying effervescence. The bulk of the air is usually forced out at one or two points, the small spheres rising rapidly toward the surface of the water, like the spurt of a miniature fountain.

Absorption.—The white porcelain-like kaolin is porous and readily absorbs water, though the absorbed water does not render it plastic. The amount of water absorbed is greater in the granular kaolin and least in the white porcelain variety. The per cent. of absorption by weight varies from 6.6% to 13%.

Fracture.—This kaolin has no definite cleavage, but there are flat smooth surfaces which resemble cleavage planes. These planes usually extend for only short distances and may meet other planes or curved surfaces at any angle. The fracture is distinctly concoidal in some places and very irregular in others. The fractured surfaces often resemble the surfaces of broken bisque.

Hardness.—The hardness of the white porcelain-like kaolin is usually above that of gypsum and below that of calcite, on the average it is about 2.5. There is, however, a variety which has a hardness of less than 1, being soft and plastic. This variety becomes hard on exposure to the air. The yellow and purple varieties have a hardness of 1.

Specific Gravity.—The specific gravity of the white porcelain kaolin varies from 2.00 to 2.31; white granular, from 1.90 to 1.94; yellow, from 1.94 to 2.01; purple, from 2.26 to 2.33.

Macroscopic Structure.—The unstained white material seems devoid of definite structure. (See Plate VIII.) It might be described as being, in general, coarsely granular with an occasional plate-like surface. In some places there are cell-like spaces with interior portions covered with botryoidal forms. Again, the kaolin may assume the form of concretion-

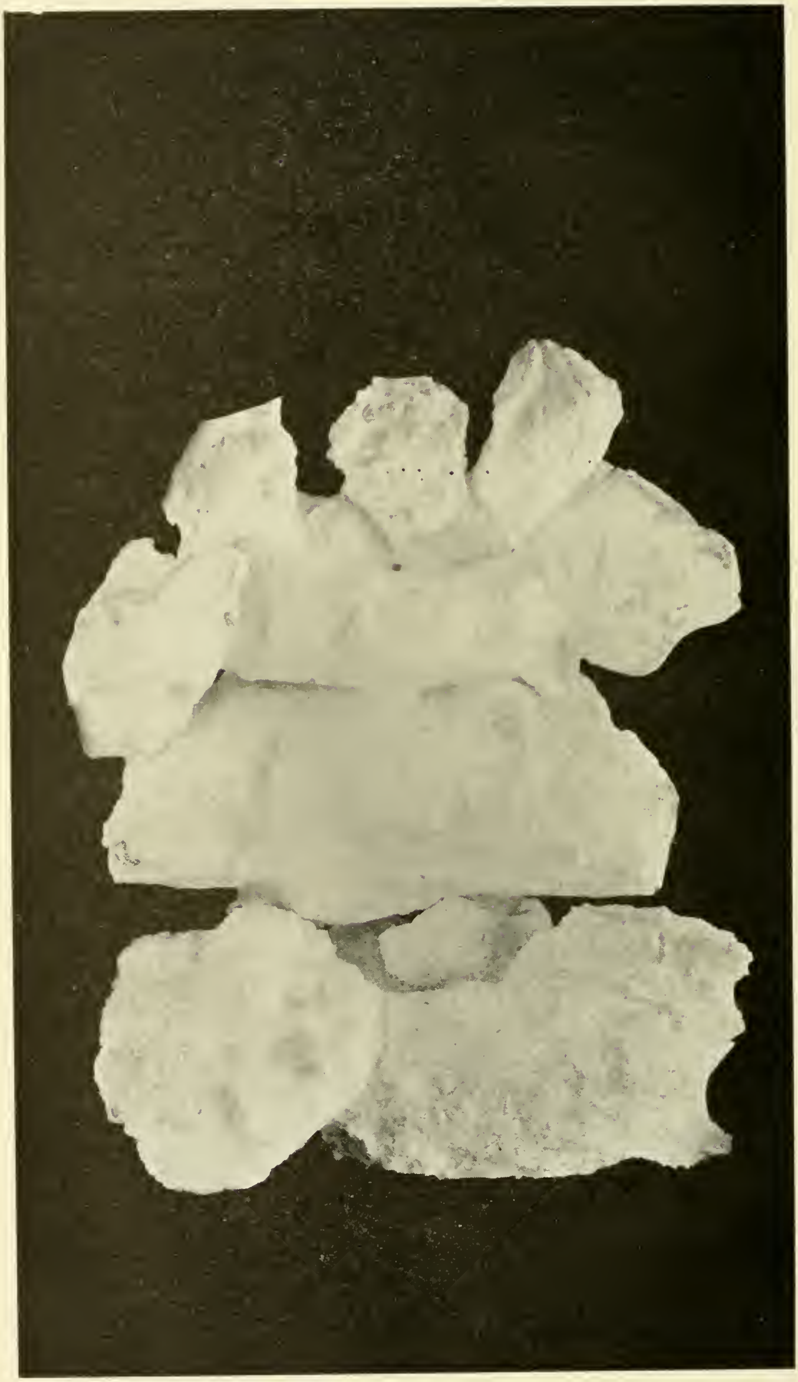

Plate VIII. Masses of white kaolin from the Gardner mine, Lawrence County.

ary masses, composed of concentric layers. The stained kaolin may be distinctly laminated, in which case yellow, brown and purple layers alternate with white. In some places the porcelain-like material exhibits a wavy laminated structure with stained lines and surfaces that are covered with projecting spherical masses of white material separating the layers of porcelain-like Indianaite, while in others it is pitted with these small white granules of clay, producing an amygdaloid-like structure. These small granules have about the same degree of hardness as the surrounding Indianaite. In some places the white Indianaite presents an irregular laminated appearance. This lamination seems to be more clearly marked in the yellow clay than in the white. In some cases, however, the laminated appearance is due to the presence of thin layers of yellow clay within the white. Concretionary masses are sometimes found in the white Indianaite. These vary in size from a few inches up to nine or ten inches in diameter. The concentric layers are separated by thin lines of black and yellow stain. The translucent form is, in places, composed of a series of small geode-like masses, arranged in a general horizontal position. The walls are about 1/8 of an inch in thickness and the diameter of the cavities from 1/10 to 1/8 of an inch. The interiors of the cavities are lined with a layer of milk-colored Indianaite which has a mammillary surface, and the cavities are sometimes wholly or partly filled with round grains of the same material. In one hand specimen five of these cavities are arranged in a line occupying a horizontal distance of two inches. Cavities of various sizes are of common occurrence in the Indianaite.

Color of Indianaite.—The purest form is white or greenish-white in color. Much of it has been stained and the most common form of the stained is yellow, due to the presence of hydrated oxide of iron. There are also brown colors, due to larger amounts of the same pigment. In some places there are purple colors and black colors, due to the presence of manganese compounds; however, some of the black stains are due to organic matter. In most cases there is no regularity in the arrangement of colors, but in some cases the arrangement of colors is in bands. The kaolin under such conditions has a distinctly stratified appearance due to alternate layers of white and yellow kaolin. (See Plate IX.)

Microscopic Appearance of Indianaite.—Under the microscope the massive white kaolin is found to be composed of minute globular granules which are often arranged in a dendritic form. The granules are translucent in appearance and have about the same index of fraction as balsam. Sometimes larger structures occur in the midst of the granules. In cross section, these are circular bodies made up of concentric rings enclosing a centrally placed nucleus. Radial lines pass through the concentrically arranged rings from the nucleus to the periphery. These circular bodies seem to break up into small

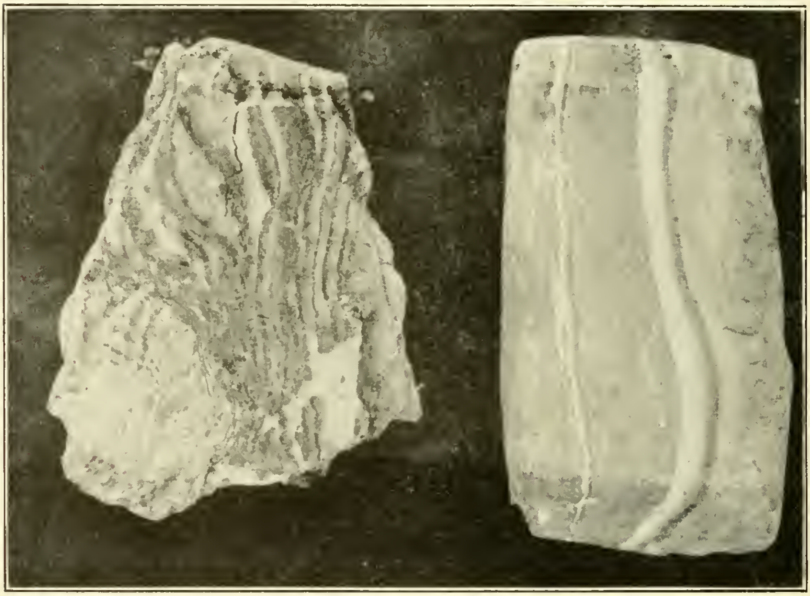

Plate IX. Masses of stained kaolin from the Gardner mine. Soft when taken from the mine.

granules of the ground mass. Several stages of the process of disintegration are recognizable. There are circles in which the boundary between the periphery and the ground mass is but faintly outlined. These will contain granules but will still show some evidence of concentric and radial structure. In other cases all but the nucleus has disintegrated by passing into the granular stage. In some cases the circular body has been completely disintegrated, with the exception of the dendritic or web-like mass of pigment which stained the nucleus. (See Plate X, Fig. B.)

It appears, also, that even this structure may become

broken up and its small dark granules be distributed among the translucent ones of the ground mass. In some sections the ground mass and the nucleus are stained yellow, but the concentric rings of the circle remain free from coloring matter. In some places there are rows of circles occupying nearly a straight line. The outer surface of these circles and the intervening ground mass are stained yellow along one side, while the opposite side may remain clear. In some circles the entire peripheral zone is stained. These circular bodies are prob-

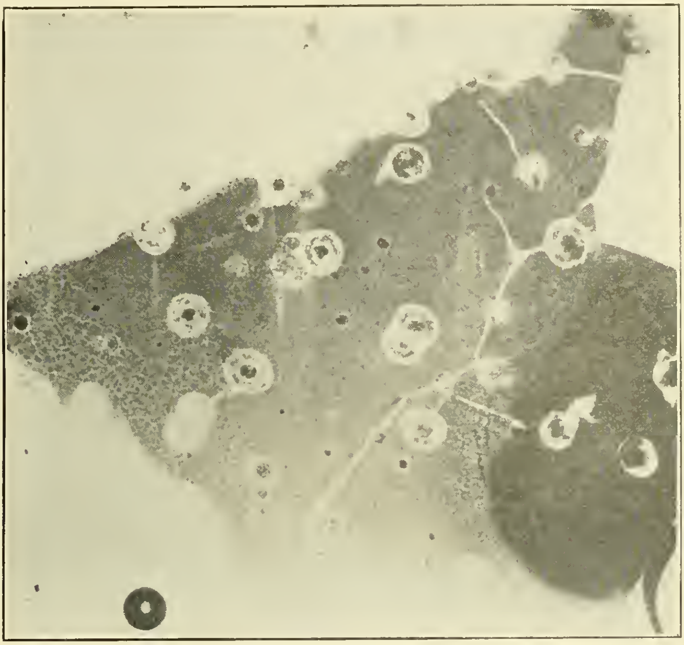

Plate X. Fig. A—Micro-photograph of spherules in white kaolin. Enlarged 250 diameters.

ably the cross-sections of oölites similar to those produced in the black clay found beneath the white kaolin. Rothpletz[1] believes that "Calcareous oölites with regular zonal and radial structure" are phytogenic; "the product of microscopically small algæ of very low rank, capable of secreting lime." The oölites found in the kaolin, since they possess a zonal and radial structure, may be phytogenic.

In the case of the ferro-aluminium sulphate referred to, spherical bodies were formed on the inside walls of the ves-

[1] Botanisches Centralblatt No. 35, 1892, pp. 265-268.

sel above the surface of the water. The surfaces of these spheres were covered with acicular projections radiating outward from the spherical surfaces. Sometimes the sulphate would pull away from the surface of the vessel under its own weight. When this occurred and fresh sulphate was deposited, it would form a thin film between the surface of the vessel and the hanging body of sulphate. This film has a convex surface and possesses both radiating and concentric lines. These lines have the same appearance as those in the circular bodies.

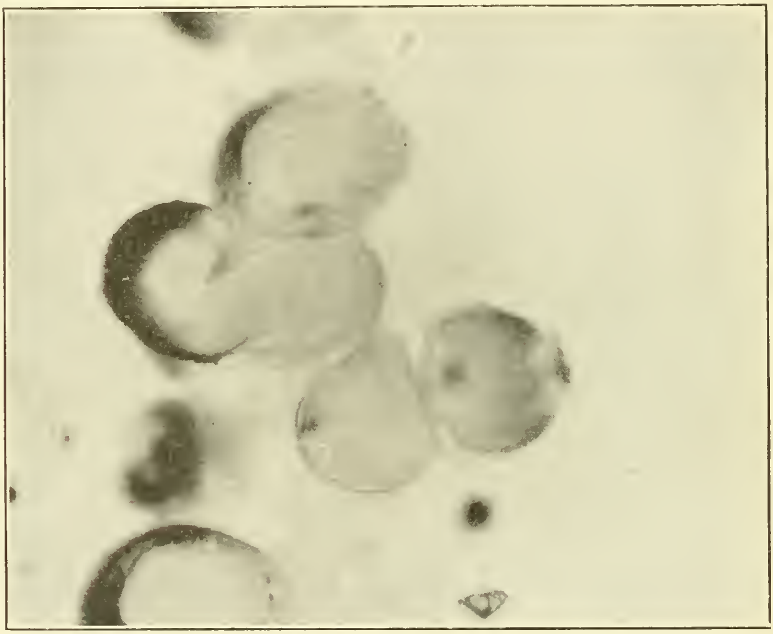

Plate X. Fig. B—Spherules enlarged 800 diameters. Have radial and concentric structure and break up into granules.

In other parts of the vessel the deposited sulphate had a botryoidal or mammillary appearance. The surfaces of the globular masses were rough. They are fastened to the surface of the vessel by sulphate of a massive structure. In some places plate-like masses were formed with their surfaces parallel with the surface of the vessel. This plate-like structure is also recognizable in the natural kaolin deposits. It would seem that in some instances the sulphate may have been changed into the silicate without change of form.

Composition.—The composition of three samples of Indianaite as published in Dana's Mineralogy is as follows:

SiO_2	Al_2O_3	H_2O	H_2O at 100°C	CaO, MgO	Alkalies	Total
39.00	36.00	14	9.50	0.63	.054	99.67
39.35	36.35	22.90		0.40	...	99.00
38.90	37.40	23.60		Undet.	...	99.90

These samples all contain less alumina than is contained in kaolinite which contains 39.5 per cent. of alumina. They approach more closely the composition of halloysite, which contains 43.5 per cent. of silica, 36.9 per cent. of alumina and 19.6 per cent. of water and it is to halloysite that Dana refers it.

OTHER ANALYSES OF INDIANA KAOLIN.

No.	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	SO_3	CaO	MgO	K_2O	Na_2O	H_2O	Comb.	Total.
1	41.82	32.65	.29	.04	.085	.40	.....	.12	tr.	18.47		93.875
2	39.00	36.00	......	......	.....	.....	.63	.....	.54	9.50	14.00	99.67
3	39.35	36.35	......	......	.....	.40	.....	.....	......	22.90		99.00
4	38.90	37.40	......	......	.....	.....	.....	.....	......	23.60		99.90
5	45.90	40.31	......	......	.....	tr.	.....	.....	......	.....	13.26	99.50
				(MnO_2)								
6	47.05	37.14	tr.	.03	.....	.....	.03	.....	......	.....	15.55	99.80
7	47.13	36.76	tr.	tr.	.....	.....	.04	.....	......	.....	15.13	99.06
8	46.00	40.20	......	......	.....	.....	.20	.....	......	.....	12.62	99.02
9	44.75	38.39	.95	......	.....	.37	.30	.12	.23	.....	15.17	100.28

No. 1. Soft plastic kaolin collected by the writer. L. L. Carrick, analyst.

Nos. 2, 3 and 4. Cox, 8th Annual Rept. Ind. Geol. Sur., pp. 155-156.

Nos. 5, 6 and 7. Cox, 6th Annual Rept. Ind. Geol. Sur., p. 18.

No. 8. M. Thompson, 15th Annual Rept. Ind. Geol. Sur., p. 36.

No. 9. W. A. Noyes, 20th Annual Rept. Ind. Geol. Sur., p. 105.

ANALYSES OF ALLOPHANE.

No.	AiO_2	Al_2O_3	MgO	Na_2O	H_2O Comb.	Total
1	20	40			40.00	100.00
2	15.71	42.74	.59	26.50	14.50	99.54

No. 1. Cox, 6th Ann. Rept. Ind. Geol. Survey, p. 16.

No. 2. Cox, 8th Ann. Rept. Ind. Geol. Survey, p. 156.

The allophane is a bluish colored mineral which occurs in the white kaolin. Sometimes it forms a layer of irregular thickness above sandstone or conglomerate masses in the kaolin. In other places it is a part of concretion-like masses in the kaolin. When it is exposed to the air it breaks down into the granular form of kaolin and loses its bluish tint.

CHAPTER III.

THE GEOLOGICAL CONDITIONS OF OCCURRENCE OF INDIANA KAOLIN AND THE ASSOCIATED ROCKS.

Mode of Occurrence.—The kaolin of Indiana lies in beds apparently interstratified with sandstones and shales. The kaolin, however, is more irregular in thickness and distribution than the adjoining beds.

One horizon of the kaolin occurs at the contact between the Chester shales and the Mansfield sandstone of the Pennsylvanian. The surface of the Chester was eroded prior to the Pennsylvanian deposition and the Mansfield was laid down upon this eroded surface. The position of the elevations and depressions in this old Chester surface can still be determined, and it is in connection with the depressions that the best deposits of kaolin have been found. For instance, on the Gardner place the contact of kaolin and Mansfield occur at about 700 feet above sea level, while only one-half mile south the limestone of the Chester occurs at 790 feet, while one mile north the Mansfield contact occurs at 720 feet above sea level.

The kaolin along the contact is closely associated with the Mansfield sandstone and with Chester shales. It always has Mansfield sandstone above and Chester shales below. In some cases the kaolin has passed upward into the sandstone a distance of as much as ten feet, apparently replacing a portion of the sandstone. At one point below the kaolin there is a dark colored clay resting on Chester shales. The dark colored clay contains quartz pebbles similar to those found in the Mansfield, and it would seem that the dark colored clay was of Pennsylvanian age.

The kaolin underlying the Mansfield rests on the Elwren shales at some points, on the Cypress shales at others, on the Golconda shale at others, and on the Hardinsburg shales at other points. In some places the limestone above the shale was removed over a given area and a basin formed by pre-Pennsylvanian erosion. Some one of the Chester shales forms the bottom of the basin and its walls are composed of Chester shales and limestones. Bowlders of limestone, erosion remnants, are scattered over the surface of the basin. This basin was then filled with the Mansfield sediments.

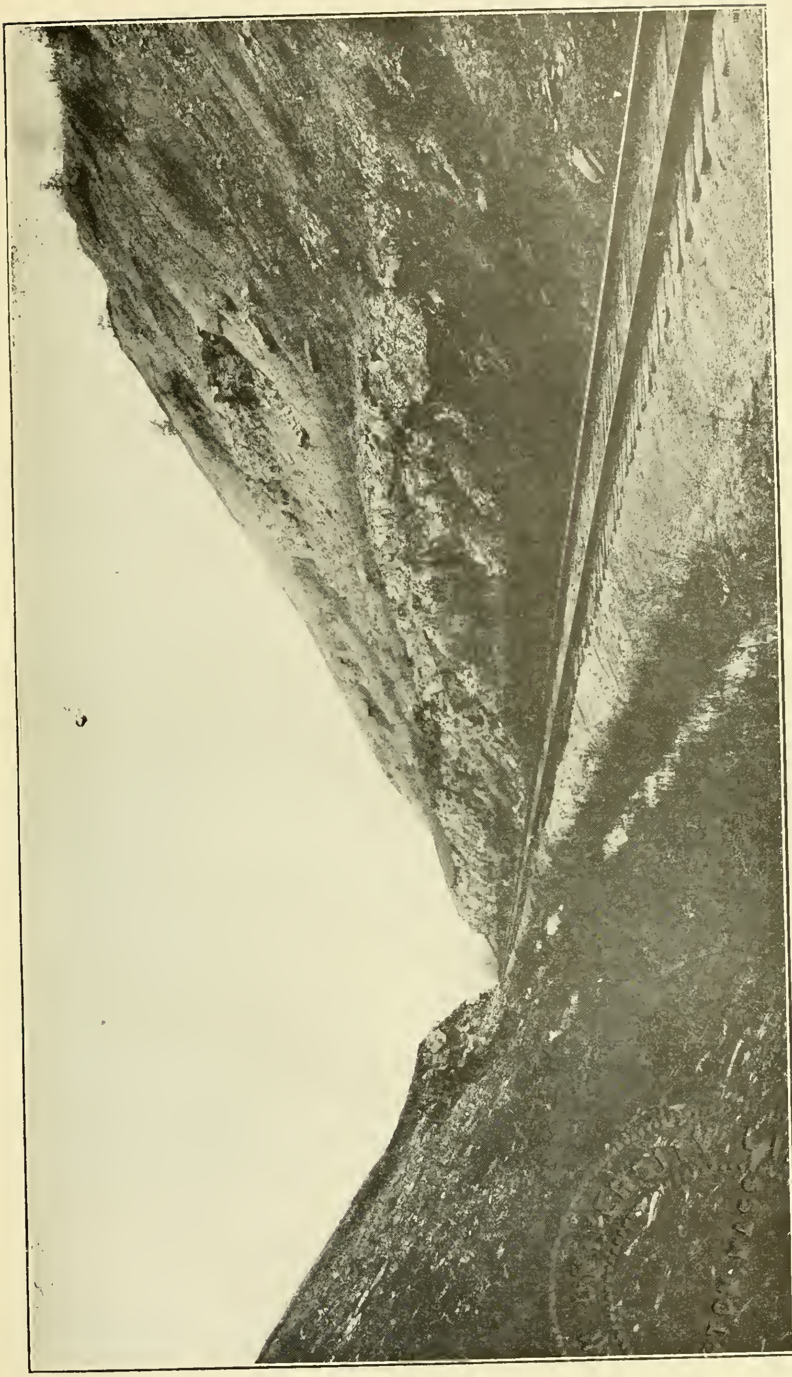

Plate II. Cut east of Huron on B. O. R. R. Sample shale at bottom, Beaver Bend limestone, Brandy Run shale, Reelsville limestone, Elwren shale and Beech Creek limestone in order above.

Kaolin in the Chester.—The Chester epoch of the Mississippian period in Indiana is represented by a series of shales, sandstones and limestones. All except some of the upper

Plate III. Masses of kaolin from the Gardner mine. Two of these masses were plastic and soft when removed and shrinkage cracks developed.

members of the Chester group are represented in the railroad cut east of Huron. (See Plate II.) Resting on the Mitchell limestone at this place is 4 or 5 feet of Sample shale contain-

ing a thin layer of coal. This is followed by 14 feet of Beaver Bend limestone; followed by 24 feet of Brandy Run shale and sandstone; followed by 6 feet of Reelsville limestone; followed by 42 feet of Elwren shales and sandstones; followed by 15 feet of Beech Creek limestone; followed by 6 feet of Cypress sandstone. At Dover Hill in Martin County about 30 feet of Cypress sandstone is followed by 30 feet of Golconda shales and limestones; followed by 20 feet of Hardinsburg sandstone and shales; followed by 25 feet of Glendean limestone; followed by sandstone, probably Tar Springs, which is followed by the Mansfield sandstone.

The Chester contains kaolin at several horizons. On the George Cleveland farm in Orange County kaolin was found in a cave lying beneath the Sample sandstone and resting on the Beaver Bend limestone. The kaolin was formed from a thin layer of shale lying between the limestone and the sandstone. In both Lawrence and Monroe Counties kaolin occurs beneath the Elwren sandstone and is formed from the shales of that division of the Chester. In Lawrence and in Martin Counties, kaolin occurs below the Cypress sandstone. In a cave in the Beech Creek limestone in Section 1 in Mitchelltree township in Martin County about 18 inches of kaolin rests on the Beech Creek limestone and is succeeded above by about 5 feet of shaly sandstone which in turn is succeeded by 25 feet of massive Cypress sandstone.

Conditions of the Outcrops.—Occurrences of the pure white kaolin at the outcrop are rare. Small particles of white kaolin are found distributed through the detritus covering the outcrop, and such occurrences are not uncommon. The weathered portion of the bed at and near the outcrop consists of a mahogany colored clay. This mahogany clay contains small fragments of the white kaolin, especially in the upper portion underneath sandstone ledges that are fairly compact and unfractured. The mahogany clay has doubtless in some instances at least originated from the staining of white Indianaite by oxide of iron. The olive-green shales in places are changed into a maroon colored clay which passes into mahogany colored clay. The following analysis shows the composition of a sample of this mahogany clay:

Plate IV. Six feet of white kaolin in the Gardner mine. Large mass of imbedded sandstone at the left.

ANALYSIS OF MAHOGANY CLAY.

Silica	33.04%
Alumina	17.33%
Ferric oxide	27.96%
Manganese oxide	2.22%
Calcium oxide	1.52%
Magnesium oxide	1.11%
Titanium oxide	.69%
Alkalies	1.77%
Volatile matter	13.87%
Total	99.51%

Structural Features of the Kaolin.—In the mass the kaolin occurs as either coarsely granular material or as concretionary or other masses of porcelain-like appearance. These porcelain-like masses fracture into irregular fragments, exhibiting on some surfaces a conchoidal fracture. In some places the porcelain-like material exhibits a wavy laminated structure with stained lines and surfaces that are covered with projecting spherical masses of white material separating the layers of porcelain-like kaolin. In some places the porcelain-like material is pitted with these small white granules of clay, producing an amygdaloidal structure. These small granules have about the same degree of hardness as the surrounding kaolin. Under the microscope the porcelain-like kaolin exhibits a granular appearance, the grains being apparently spherical in form and in some sections arranged in a dendritic structure. The dendritic structure may be due to the loss of water and consequent shrinkage when the section is heated during its preparation. In some places the white kaolin presents an irregular laminated appearance. This lamination seems to be more clearly marked in the yellow clay than in the white. In some places the clay presents a laminated appearance due to the presence of thin layers of yellow clay within the white. (See Plate III.) Concretionary masses are sometimes found in the white kaolin. These vary in size from a few inches up to nine or ten inches in diameter. The concentric layers are separated by thin lines of black and yellow stain. The white kaolin is, as a rule, hard, but in some places is soft and very plastic, resembling in appearance a white ball of clay. In other places the plastic clay is yellow in color and is interstratified with yellow or brown sand.

Both varieties of kaolin, granular and massive, occur in a

translucent body of greenish color. They also occur in an opaque white form, in which form they resemble the interior surface of broken bisque. The translucent form is, in places, composed of a series of small geode-like masses arranged in a generally horizontal position. The walls are about 1/8 of an

Plate V. Vein-like mass of white kaolin in sandstone in Gardner mine.

inch in thickness and the diameter of the cavities from 1/10 to 1/8 of an inch. The interiors of the cavities are lined with a layer of milk-colored kaolin which has a mammillary surface. The cavities are sometimes filled or partially filled with rounded grains of the same material. In one hand specimen

five of these cavities are arranged in a line occupying a horizontal distance of two inches. Cavities of various sizes are of common occurrences in the Indianaite. The porcelain-like form fractures irregularly and also with a conchoidal fracture. Its conchoidal fracture resembles that of flint, and its irregular fracture that of chert. The composition of a sample of the mine-run white clay is as follows:

ANALYSIS OF MINE-RUN SAMPLE OF WHITE INDIANAITE.

Silica	40.48
Alumina	39.60
Hygroscopic water	5.01
Combined water	15.03
Ferric oxide	.11
Total	100.23

Layers of coarse or disconnected masses of coarse sand or sandstone, stained with iron oxide and containing small particles of white kaolin, occur in many portions of the bed of kaolin. (See Plate IV.) The separated block masses of sandstone are sometimes almost, if not completely, surrounded with white Indianaite. Occasionally a mass of sandstone is penetrated by a vein-like body of kaolin. (See Plate V.) In one instance a triangular piece of sandstone occurs surrounded on all three sides by white kaolin. (See Plate VI.) In another instance a dark laminated neck-like body of clay extends from a floor of similar material up into the kaolin. This clay contains pellet-like bodies of white clay which are soft and plastic in situ, but hard and granular when dry. This clay also contains white quartz pebbles such as are found in the basal sandstone members of the Pottsville. The clay has a fetid odor similar to that of muck. It also contains concretionary masses of marcasite. At another point in the bed of kaolin next to the sandstone roof there were white and dark layers of kaolin above, then a layer of white, partially laminated kaolin below, then a four-foot layer of sandstone occupying the lower part of the deposit. The sandstone layer was divided near its central portion by a vien of white kaolin extending through the four-foot layer of sandstone. The sandstone layer has a thin fin extending upward obliquely into the white kaolin. This fin is about five feet in length and one foot thick in its thickest portion. Above the lens of sandstone there are several concretion-like masses of kaolin, the porcelain-like layers of which are separated by dark stains. (See Plate VII.)

Plate VI. Triangular mass of sandstone in Gardner mine surrounded by white kaolin. Coarse grains of sand cemented with kaolin.

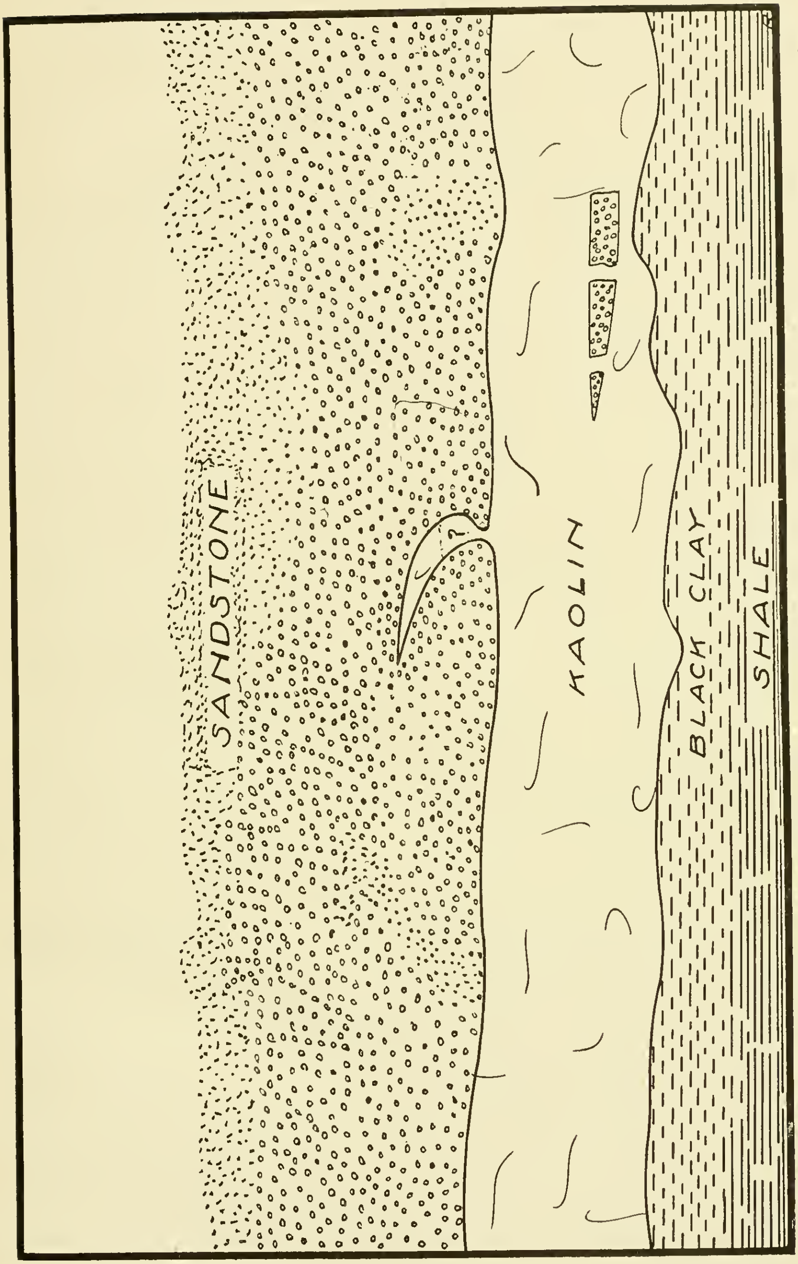

Plate VII. Showing kaolin passing up into sandstone, or a lens of kaolin in sandstone. Also sandstone in kaolin. Gardner mine.

Associated Rocks.—The rock overlying the kaolin in all cases as far as observations have extended is sandstone. This sandstone is assigned in some instances to the Pennsylvanian, in others to the Mississippian. The character of the layer in immediate contact with the upper surface of the kaolin is variable. In some places the roof is composed of soft pink sandstone; in other places the sandstone is conglomeratic; in other places it is firmly cemented and almost iron ore in composition. The underlying rock is in most places a shale or clay. In one instance a small body of white kaolin is completely surrounded with sandstone. In other instances there are thin layers of sandstone underlying the kaolin. In some places there are lens-like masses of limonite occurring at the base of the kaolin. These masses of limonite contain quartz pebbles, characteristic of the Pottsville formation. Within the mahogany clay irregular eroded masses of limestone are sometimes found. Microscopic sections of this limestone show it to be highly fossiliferous. Within the kaolin bed sandstone, sand, conglomerate and concretionary masses of limonite constitute the principal foreign materials of consequence. A sample of the limonite taken from the base of the kaolin has the following composition:

ANALYSIS OF LIMONITE FROM BASE OF INDIANAITE.

Iron oxide	83.73
Insoluble matter	2.56
Loss on ignition	12.02
Total	98.31

Quantity of Indianaite.—A question of absorbing interest is, What is the quantity of white clay? It is a question which under the present state of development is difficult to answer. If one were to base his judgment upon the number of outcrops he would be compelled to say that the quantity was large. If he bases his judgment upon the results of the meager development or upon the visible quantity of mahogany clay he would be forced to a similar conclusion. After going over the greater part of the field, the judgment of the writer is that there is a large quantity of clay of all grades. In fact that it underlies thousands of acres of land in the counties mentioned, how much of it is of the pure white variety cannot be estimated from data which is at hand at present, but that the total amount is large, is probable.

CHAPTER IV.

ORIGIN OF INDIANAITE.

The question of the origin of Indianaite has been the source of much speculation and discussion. Two theories of origin have been advanced in the geological literature of Indiana.

The Coal-Ash Theory.—Leo Lesquereux[1] suggested that the clay was formed by the burning out of a bed of coal. Speaking of the clay near Dover Hill, he says: "On both sides of the place where this coal is worked there is a bank of very soft ochrous clay, a true powder, as fine as flour, without any trace of coal, though occupying exactly the same horizon. It is overlaid by a clay iron ore, which looks as if it had been roasted. I consider this local formation as the result of the burning of the bank of coal at places where it was exposed along the creek." Assuming, as suggested by Lesquereux, that the clay was formed from the ash of the coal, it would require a bed of coal, the thickness of which would be far beyond any recorded thickness. The coal bed which Lesquereux suggested had been burned out is Coal 1, the ash of which is generally well under 10 per cent. Assuming the ash to be 10 per cent., it would require 110 feet of coal to produce the maximum thickness of kaolin. If we assume an ash of 25 per cent. it would still require a bed of coal of a thickness of 44 feet to produce the maximum thickness of kaolin. If it be assumed that kaolin was formed from beds of clay lying adjacent to the coal, it would seem, as suggested by Reis[2], that the burning of the coal would produce dehydration of the clay, evidence of which is lacking. The writer has seen clays which have been dehydrated by the burning out of coal beds in several States, but he never saw anything approaching the kaolinization of the dehydrated clay. If a bed of coal had been burned out, it would cause a disturbance of the overlying sandstone, break it up, fracture, fault and possibly brecciate it. No evidence of such disturbance has been detected, although the writer has examined much of the sandstone roof above the kaolin which has already been mined. Moreover, it is prob-

[1] See Leo Lesquereux's report of the Geological Reconnaissance of Indiana, 1862, p. 320.

[2] See Reis' Clays, 1914, p. 351.

able that the burning of the bed of coal in contact with the sandstone would cause the fusion of the ferruginous sandstones of the latter, at least at the point of contact. No evidence of such fusion exists, or even the slightest evidence of incineration.

The writer examined the outcrop of kaolin at Dover Hill and found that it lies at the contact of the Mansfield sandstone with the Hardinsburg shale. Five hundred feet to the east no kaolin is present, but twenty feet of sandstone lies below the Mansfield and ten feet of limestone is exposed below the sand-

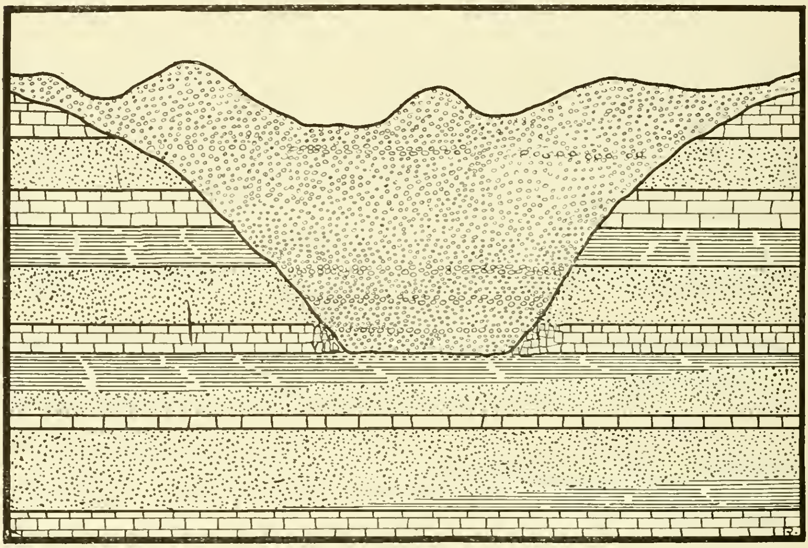

Plate XI. Diagram showing nature of the Chester-Mansfield contact in Martin County. Vertical scale greatly exaggerated. Lowest contact on the Elwren shale in this section.

stone. No coal occurs at the elevation or horizon of the kaolin, but coal occurs on the east side of Dover Hill in the Mansfield at a higher elevation than the kaolin. There is a pink colored, coarse grained sandstone overlying the kaolin on the north side of Dover Hill, but about one-quarter of a mile southwest there is an outcrop of kaolin at about the same elevation underlying sandstone containing limonite. In case of burning out of coal underlying it the limonite would have lost its water of crystallization and been converted into hematite. At this point the kaolin occurs at the Mississippian-Pennsylvanian contact, (see Plate XI) but the coal occurs above the contact

in the Pennsylvanian. At Dover Hill the coal is higher than the kaolin when referred to either sea level or stratigraphical position. At no place has the writer seen a coal bed near a bed of kaolin at the same stratigraphical horizon.

The method of making road ballast by burning log heaps, covered with clay, is a familiar one. The material produced is very similar to that of the dehydrated clay of burned-out coal beds. The latter is, if anything, a little more vitrified. Burned clay ballast has been used for years on wet marshy lands and not noticeably hydrated. The point west of Shoals mentioned by Ashley[1] is not at the same elevation as the coal. The kaolin is about seven feet higher than the coal.

The kaolin underlies massive conglomeratic sandstone and has associated with it masses of limonite. Chester shales lie below the kaolin, so it is evident that the kaolin lies at the contact between the Mississippian and the Pennsylvanian. The coal occurs about 500 yards west of the kaolin outcrop and lies between beds of shale. This shale seems to belong to the Pennsylvanian. It underlies a ledge of massive sandstone similar in appearance to that under which the kaolin lies. The Mississippian-Pennsylvanian contact must be below this shale. The line of unconformity dips strongly toward the west at this point. The kaolin is deposited on the line of the unconformity and the coal is deposited above the unconformity, but seven feet lower than the kaolin. Though it does not occur at this point it is entirely possible for coal to be deposited on the line of the unconformity at one point and the conditions favorable to the formation of kaolin to occur at another point on the unconformity. While the kaolin of the Pennsylvanian is, in all outcrops observed, connected with the unconformity, in no case has the coal been directly connected with the unconformity, as at least a few feet of shales intervene between the coal and the unconformity. The fact that limonite exists in and above the kaolin at this point increases doubt of the burned-out coal theory.

Kaolin occurs at three different horizons in the Chester, occurring under the Sample sandstone, the Elwren sandstone and the Cypress sandstone. In one place the kaolin under the Elwren has a thickness of six feet. Very little coal occurs in the Chester in Indiana. A few inches of coal occur at widely

[1] See Ashley's 23rd Annual Report, Geol. Survey of Indiana, p. 931.

separated points in the Sample and in the Elwren. It seems an assumption impossible of demonstration that the kaolin of the Chester was formed by the burning out of coal beds.

Residual Limestone Theory.—This theory was suggested by E. T. Cox,[1] who in describing a geological section in Lawrence County containing kaolin, says: "It will be seen from the above section that the clay lies immediately beneath the Millstone grit or pebbly conglomerate of the coal measure and here occupies the place of a bed of Archimedes limestone which is seen in situ about two miles southwest of the mine. The overlying sandstone is very ferruginous, and the base, where exposed to the weather, has decomposed and covered the clay in places to a depth of eight or ten feet with ferruginous sand and pebbles. There is a constant oozing of water from this sandstone which has, no doubt, played an important part in the chemistry of the clay and hematite deposit, for though similar in its chemical composition to kaolin, this clay differs physically and owes its origin to an entirely distinct set of causes and effects. While the former is derived from the decomposition of the feldspar of feldspathic rocks, such as granite porphyry, etc., the porcelain clay of Lawrence County has resulted from the decomposition, by chemical waters of a bed of limestone and the mutual interchange of molecules in the solution, brought about by chemical precipitation and affinity. Where cavities existed in the limestone at the base of the strata, there the chalybeate water found the oxygen to change the carbonate into sesquioxide of iron, which finally filled up the cavity. In places you can trace the passage of the ferruginous water along irregular joints in the clay bed, by the iron-stained path which it has left, to the brown hematite ore which lies in a mass at the bottom. The largest beds of hydrated sesquioxide of iron both in Europe and America are found at the base of the Millstone grit and filling up cavities in the cavernous sub-carboniferous limestone."

It appears that the conclusion arrived at by Cox, that the kaolin has been formed by the decomposition of a bed of limestone, "which is seen in situ, 2 miles southeast of the mine," is based on an error. The Archimedes limestone mentioned lies about eighty feet higher than the position of the kaolin because of the unconformity which exists between the Chester

[1] See E. T. Cox, 6th Annual Report of the Geological Survey of Ind., 1874, p. 15.

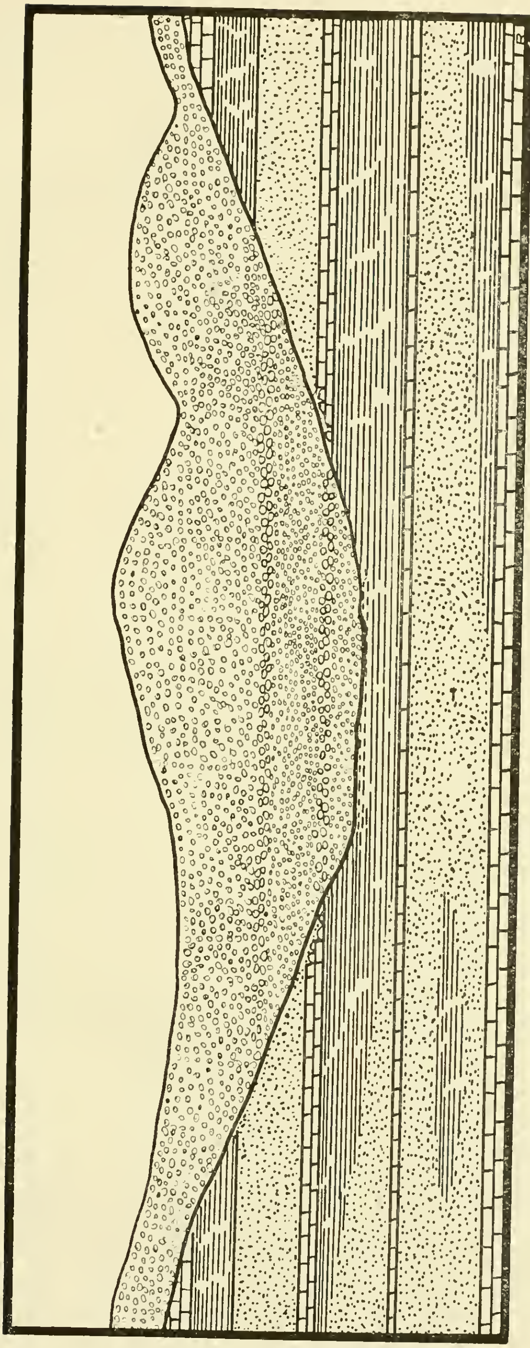

Plate XII. Diagram showing nature of the Chester-Mansfield contact in Lawrence County. The best kaolin is found in the bottom of such depressions. Vertical scale exaggerated.

and the Pennsylvanian at this point. In the basin in which the kaolin lies more than ninety feet of Chester rocks have been cut out. (See Plate XII.) Although there are in this region numerous occurrences of sandstones overlying beds of limestones and these limestones have been and are being decomposed under the influence of meteoric waters, there exists no evidence of the formation of kaolin, even in its incipient stages under the conditions suggested by Cox. If the kaolin were formed by a dissolving out of beds of limestone, underlying sandstones, we should expect to find evidence of disturbance in the overlying sandstone layer. No evidence of such disturbance exists.

The Mississippian limestones contain a very small amount of insoluble materials, perhaps not more than 10 per cent. at the most, and it would require the decomposition of a bed of limestone of the thickness of at least 40 feet, in order to produce the maximum thickness of kaolin. It has been suggested[1] that part of the material composing the kaolin was brought down by meteoric waters from the overlying sandstone. This view seems to me untenable, because there are numerous caves occurring in limestones in this region which have an overburden of sandstone and there are no evidences of these cavities being filled with material brought from above, although there is abundant evidence of percolating waters.

The occasional occurrence of limestone bowlders in connection with kaolin outcrops is a matter requiring explanation. The writer believes them to be erosion remnants left on the surface of the Chester shales during the pre-Pennsylvanian period of erosion. The facts that the kaolin is always found at the contact and overlying Chester shales and that the limestone bowlders belong to Chester limestones, seem to support this view. The conditions are represented in the diagram in Plate XIII. In Section 8, a mile and a half east of Huron on the Wilson farm, there is an outcrop of Beech Creek limestone resting on Elwren shale with a spring at the contact. Above the limestone the Cypress sandstone forms a structural terrace on which the Wilson house stands at an elevation of 720 feet above sea level. No Mansfield is present at this point and no kaolin. One-fourth of a mile northwest of the spring the fifteen feet of Beech Creek limestone and forty feet of

[1] See Thompson, 15th Annual Report, Indiana Geological Survey, 1886, p. 37.

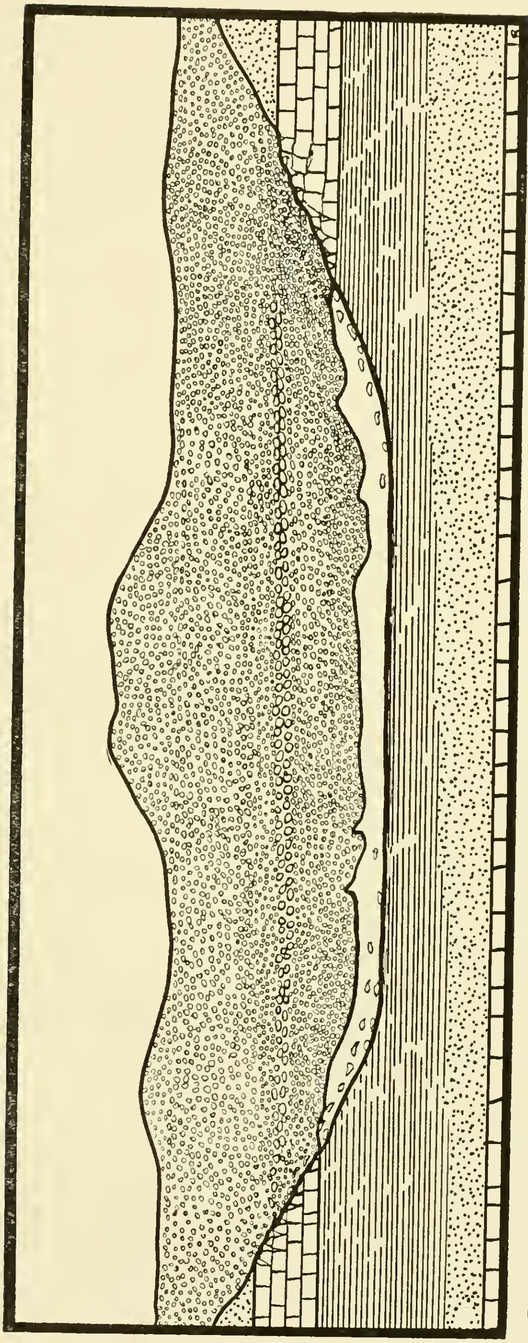

Plate XIII. Diagram showing position of a kaolin bed along the Chester-Mansfield contact. Kaolin resting on Elwren shale. Limestone boulders scattered on the eroded surface of the shale.

Cypress have been cut out and the Mansfield rests on a bed of kaolin which in turn rests on the Elwren shale at an elevation of 660 feet above sea level. A few limestone bowlders have been found in the mahogany clay associated with the kaolin. The limestone undoubtedly gradually thickens toward the spring, where the full thickness is revealed. One mile north of the kaolin the Mansfield rests on the Cypress at an elevation of 695 feet above sea level. It is evident that the kaolin has been formed on the Elwren shale in a pre-Pennsylvanian basin or trough.

Kaolinization.—Were such deposits of white kaolin as those of Indiana to occur in regions of profound crustal disturbance and vulcanism, no time would be lost in assigning their origin to hydrothermal action. But when the geological occurrence does not justify a belief in hydrothermal conditions the problem assumes a more difficult aspect. Upon the discovery of such deposits in practically undisturbed sedimentary rocks one is naturally inclined to assign their origin to weathering, the chemical action of meteoric water or possibly the refinements of selective deposition. So, for Cox to appeal to the weathering of limestone as the origin of the Indiana kaolin was natural, as it was also for the Thompsons to support him in this view. Weiss[1] emphasizes the importance of moor waters as agents of kaolinization, asserting that they contain all the necessary compounds, such as carbon dioxide and organic matter, while oxygen, which is detrimental to the process, is absent.

To confirm this view experimentally, he proceeds as follows:

He introduced 50 grams each of a greenish and of a yellow clay in separate flasks of 5 liters capacity, to which flasks a mixture of moor water and distilled water was added. He passed carbon dioxide through one flask, and to the other he added grape-sugar and yeast to bring about fermentation, thus generating carbon dioxide. In later experiments the moor water was replaced by an extract obtained from the treatment of fresh peat with distilled water. The flasks were kept at a temperature of 45°-50° and shaken daily for a period of nine weeks. The sediments were removed, washed with distilled water, and, on analysis, the following results were obtained:

[1] Zeitschr. f. Geologie, 1910, p. 353.

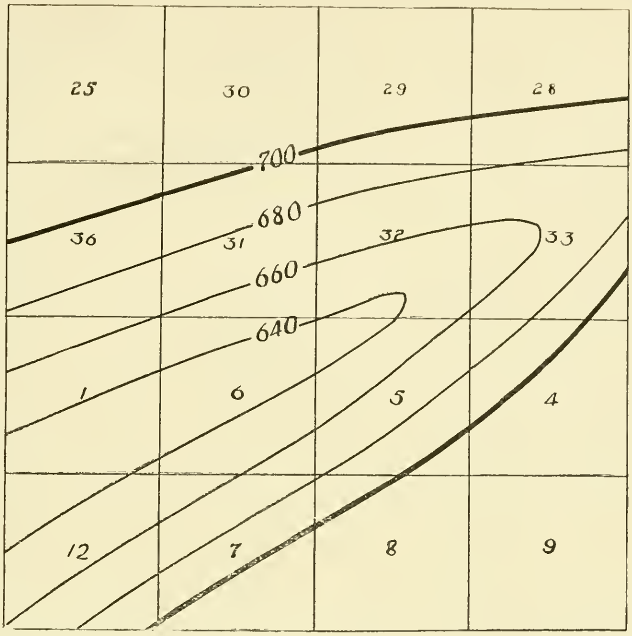

Plate XIV. Diagram showing contour lines drawn on the Chester-Mansfield contact east of Huron. Contour interval 20 feet. Kaolin occurs in the basin.

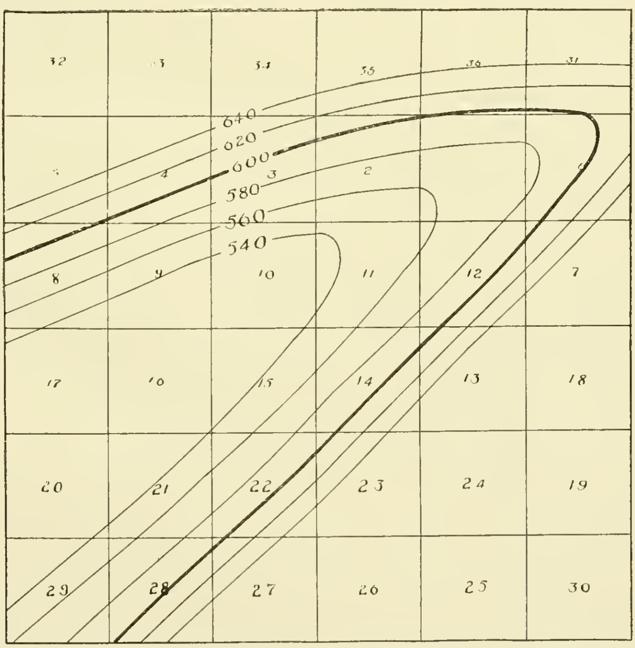

Plate XV. Diagram showing a pre-Pennsylvanian basin carved in the Chester northeast of Dover Hill in Martin County. Contours drawn on the contact. Contour interval 20 feet.

YELLOW CLAY.

		Original material (dried).		Sample treated with moor water and CO_2.		Sample treated with grape-sugar and yeast.
SiO	(A)	60.90	(B)	62.80	(C)	62.15
Al_2O_3		24.74		30.84		29.84
Fe_2O_3		4.61		1.14		1.64
CaO		3.05		0.60		1.69
MgO		2.43		1.70		1.49
Na_2O		2.05		1.00		0.88
K_2O		3.20		2.40		3.03
		100.98		100.48		100.72

GREENISH CLAY.

SiO_2	(D)	56.85	(E)	55.22	(F)	55.10
Al_2O_3		30.22		34.90		35.80
Fe_2O_3		2.82		1.25		1.04
CaO		2.18		2.13		2.01
MgO		2.47		2.05		2.10
Na_2O		2.26		0.97		1.60
K_2O		3.72		3.20		2.50
		100.52		99.72		100.15

The ratio of aluminium oxide to silicon dioxide in the above sample is as follows:

(A)	Al_2O_3 : SiO_2	40.62 : 100
(B)	Al_2O_3 : SiO_2	49.11 : 100
(C)	Al_2O_3 : SiO_2	48.03 : 100
(D)	Al_2O_3 : SiO_2	53.16 : 100
(E)	Al_2O_3 : SiO_2	63.20 : 100
(F)	Al_2O_3 : SiO_2	64.97 : 100

As seen from the preceding analyses, the silica content of the samples decreased on treatment. But the most remarkable thing has been the increase in the proportion of alumina to silica on treatment, thus showing that the clays were approaching the composition of kaolin. The yellow clay, when kaolinized by the process described, approached, at its final stage, the composition of the greenish clay, while the latter, which was naturally nearer kaolin, passed through a higher stage of kaolinization.

It should be noted that the method of procedure of Weiss in these experiments made possible the introduction of bacteria, since they were undoubtedly present in the moor water and the fresh peat, and that these bacteria may have been partly or wholly the agents of kaolinization.

Bio-chemical Theory.—From a study of conditions in the field and from investigations conducted by the writer in the laboratory, he is led to suggest another theory of origin for the Indiana kaolin. He is not unaware of the fact that there are conditions existing which are difficult of explanation under the suggested hypothesis, but he believes they are less difficult of explanation than under those which have been proposed previously.

Stratigraphical Conditions.—The kaolin deposits of Indiana are confined to the Chester division of the Mississippian Period and to the Mansfield division of the Pennsylvanian.

The Chester formations of the Mississippian period in Indiana consist of a series of shales, sandstones and limestones. The following section exhibits the usual stratigraphic conditions and relation to the overlying Pennsylvanian:

CHESTER-MANSFIELD SECTION.

Sandstone, coarse grained, quartz pebbles, iron ore (Mansfield)	100–200′
Unconformity—Kaolin in places	0–11′
Sandstone, fine grained, massive (Tar Springs)	30–45′
Limestone (Glendean)	15–25′
Sandstone, ripple marked, thin bedded (Hardinsburg)	25′
Limestone with shale (Golconda)	50′
Sandstone with shale (Cypress)	20–35′
Limestone breaking into irregular blocks (Beech Creek)	12–16′
Sandstone and shale (Elwren)	30–50′
Limestone weathering red (Reelsville)	4-10′
Sandstones and shale (Brandy Run)	20–50′
Limestone (Beaver Bend)	10–14′
Sandstone and shales (Sample)	25′
Limestone (Mitchell)	

The Mansfield may rest at a given point on any one of the formations of the Chester. The line of the unconformity is very steep in places, being more than one hundred feet to the mile. For instance in Section 28, in Spice Valley Township, in Lawrence County, at the north line of the section, the Mansfield rests on the Elwren shales at an elevation of 700 feet above sea level, while only one-half mile south the Golconda limestone occurs at the surface at an elevation of 790 feet above sea level. Kaolin has been found along the contact where the Mansfield rests on the shales of the Golconda, the Hardinsburg, the Cypress, the Elwren and the Sample. (See Plates XII, XIII, XIV and XV.

These shales are of highly aluminous character, as the analyses of the following samples show:

ANALYSES OF SAMPLES OF CHESTER SHALE.

Constituents:	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
Silica	61.24%	64.57%	58.40%	58.68%	59.67%
Aluminium Oxide	18.38%	18.67%	20.70%	21.39%	19.75%
Iron Oxide	4.76%	6.22%	6.58%	6.22%	7.32%
Calcium Oxide	.70%	.10%	.15%	.14%	.20%
Magnesia	1.94%	.65%	.86%	.82%	1.02%
Alkalies	3.94%	2.62%	3.16%	2.59%	2.42%
Loss on ignition	10.04%	7.17%	8.89%	8.90%	8.60%
Sulphur Tri-oxide		tr.	1.26%	1.26%	1.02%
Total	101.00%	100.00%	100.00%	100.00%	100.00%

Unweathered, these clays are of an olive-green tint, but under the action of weathering agents they assume a maroon color. The maroon color is probably produced by an iron stain which is formed by the oxidation of pyrite in the shale. Under certain conditions the maroon shale is changed to a deeper red, mahogany colored clay. The mahogany clay often contains small particles of white kaolin.

The composition of a sample of the mahogany clay is given in the following analysis:

ANALYSIS OF A SAMPLE OF MAHOGANY CLAY.

Constituents:	Per Cent.
Silica	33.04
Alumina	17.33
Ferric oxide	27.96
Manganese	2.22
Calcium oxide	1.52
Magnesium oxide	1.11
Titanium oxide	.69
Alkalies	1.77
Volatile matter	13.87
Total	99.51

During the erosional period in the Mississippian, large quantities of this mahogany clay and the underlying shale were removed, bleached, somewhat purified and redeposited with organic matter. The same process occurred during the erosional period, existing between the emergence of the Mississippian and the deposition of the Pennsylvanian.

During the early stages of the Pennsylvanian, deposition of a portion of these clays were worked out, sorted and redeposited along with organic matter. These deposits of clay were further purified by a bio-chemical process, mentioned later. The method of separation of the pure Indianaite from the impure clay was revealed in one locality of Lawrence County, where there is a bed of kaolin overlying a bed of dark colored laminated clay, containing small globules of the soft white kaolin. The white clay appears to be composed of minute granules, and to have been secreted by micro-organisms. The method of deposition of a part of the kaolin in this particular instance seems to be somewhat as follows: The porous layer of dark colored clay becomes filled with water from the surface and the secreted kaolin is carried upward and is deposited against the lower surface of the kaolin bed as the water is evaporated. Gradually the layer of white kaolin becomes thick by the constant addition of material to the underside. The porous nature of the kaolin permits the free passage of the water upward, so that the process is not checked even after there has been considerable accumulation of the kaolin. The irregularity of the depositional surface is conspicuous and will assist in explaining the irregular structures occurring in the kaolin.

The white granules of kaolin which occur in the clay may be produced by the action of aluminium sulphate or ferro-aluminium sulphate upon quartz sand and pebbles in the clay, but a large part of it is probably due to bacterial elaboration, as will be explained later. There is also another source of the kaolin. When during periods of humidity an abundant supply of water is brought in contact with the clay containing the aluminium sulphate and the latter rises, comes in contact with beds of sandstone and is converted into Indianaite.

The ferro-aluminium sulphate is produced by the oxidation of pyrite in the shales or in limestones included in the shales, assisted by the action of bacteria. By the oxidation of pyrite, sulphuric acid and ferrous sulphate, melanterite is formed. The sulphuric acid attacks the aluminium silicate of the clay, forming alunogen, hydrous aluminium sulphate, ($Al_2(SO_4)_3$, $18H_2O$). This compound has the following composition: Supphur trioxide 36 parts, alumina 15.3 parts, water 48.7 parts. The melanterite, hydrous ferrous sulphate, ($FeSO_4$, $7H_2O$) is

composed of sulphur trioxide 28.8 parts, iron protoxide 25.9 parts, water 45.3 parts. Both of these minerals are readily soluble in cold water, and it seems that they are absorbed by sulphur bacteria, robbed of part of their sulphur and possibly

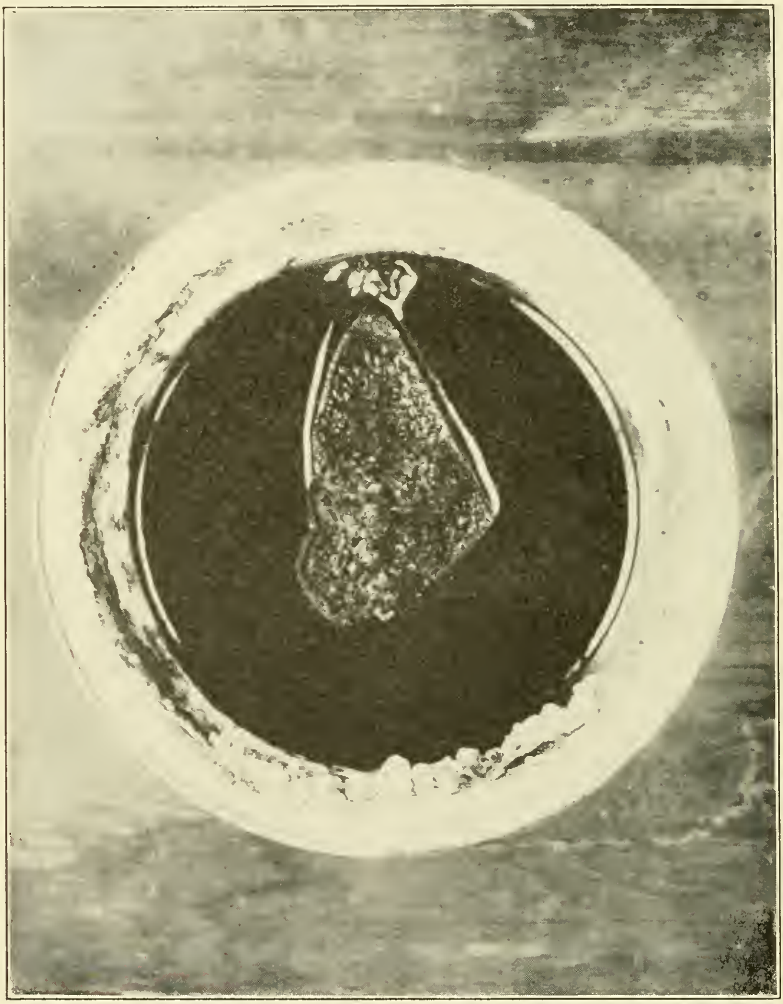

Plate XVI. Aluminium sulphate from black clay passing through sandstone and collecting on upper surface, also on walls of pan.

secreted as a ferro-aluminium compound such as halotrichite ($FeSO_4Al_2(SO_4)_3, 24H_2O$), the composition of which is sulphur trioxide 34.5 parts, alumina 11 parts, iron protoxide 7.8 parts, water 46.7 parts. (See Plate XVI.)

Changes to the Silicate.—The halotrichite is carried by water until it comes in contact with sand or sandstone, where it is changed into hydrous aluminium silicate. This change may be brought about by the action of the halotrichite on very finely divided silica or it may be produced by the action of silicic acid, which is brought down from the sandstone by percolating waters, or by the elaboration of bacteria.

Experiments with Halotrichite.

Experiment I. Halotrichite was collected from the edge of the pan in which black clay, containing pyrite and bacteria was placed. The halotrichite was dissolved in water, to the solution, water glass was added, and the greenish white precipitate was obtained. This precipitate was washed with dilute hydrochloric acid and water, and a white granular crystalline powder was obtained. This powder was tested for aluminium with the cobalt nitrate solution, and the characteristic blue color was obtained. By the hydrochloric acid test and the borax bead test the presence of silica was determined.

Experiment II. Halotrichite was dissolved in water and silicic acid was added to the solution. A white precipitate was obtained which gave reaction for both alumina and silica.

Experiment III. Halotrichite was dissolved in water in a glass beaker, in which broken fragments of quartz crystals were placed. The solution was allowed to stand for three days. At the end of that time a yellow stain was noticeable in the liquid and a slight precipitation occurred in the bottom of the beaker. The precipitate was filtered out and washed with dilute hydrochloric acid and water to remove the yellow iron stain. The test was then made for alumina and silica and both were found to be present. The formation of kaolin was more rapid when bacteria were present.

Experiment IV. Some very fine sand was placed in the bottom of a glass beaker, water was poured over the sand and some halotrichite was dissolved in the water. Bacteria were added after the solution had stood for a few days, a yellowish white precipitate was noticeable on the surface of the sand. The precipitate gave reactions for alumina and silica. From time to time soil water was added and in the course of two

months the sand had almost disappeared and kaolin had taken its place.

Experiment V. Some of the black clay which had contained bacteria was placed in a glass tumbler, water was added and a colony of bacteria. A round piece of sandstone was fitted in the upper part of the tumbler above the surface of the water. The halotrichite which was formed passed through the sandstone and formed an incrusting mass on top of it. A white granular substance giving reactions for both alumina and silica was formed on the upper surface of the sandstone after standing many weeks. It was found that the ferro-aluminium sulphate was drawn upward along the surface of glass tubes to a height of more than two feet above the surface of the solution in the vessel.

An experiment was conducted by the writer which demonstrated a probable mode of deposition of a portion of the kaolin. Into a pan of enamelware he placed some of the dark colored clay, taken from beneath the layer of kaolin and covered the clay with distilled water to a depth of an inch. The pan was then placed in a room, the temperature of which was kept at about 70 degrees Fahrenheit. In the course of time a deposit of white and bluish-green colored ferro-aluminium sulphate was deposited in a ring, just above the water, on the inside wall of the pan. The rate of deposition varied at different points, so that the ring of deposited sulphate was very irregular in form, the irregularity extending to all surfaces. The deposition of the sulphate in no way seemed to interfere with the evaporation of the water, which probably passed freely through the sulphate because of its porous nature.

Later, a further experiment was tried. Three holes were drilled in a thin piece of sandstone; into these holes three wooden pegs were inserted. The table thus formed was placed on its pegs in the pan containing the dark colored clay. The lower portion of the sandstone was separated from the clay by the space of one inch. Water was then poured into the pan until its level stood not quite to the top of the sandstone. The pan was placed under the same conditions as before, and in the course of 24 hours sulphate began to make its appearance upon the top of the sandstone. During the next 24 hours it had formed little mounds and pinnacles, one-fourth of an inch high, on the top of the sandstone. (See Plate XVI.) In

the course of a few days it had obtained a thickness of one-half inch. Little globular masses were formed on the upper surface of the sulphate. Surfaces of these globules (See Plate XVII) were covered with spine-like projections. On a portion of the surface of the pan a botryoidal form of the sulphate was deposited. The grape-like masses were not smooth and they were united at their bases to a massive layer of sulphate which was attached to the surface of the pan. When the mass of sulphate collected on the side of the pan became heavy

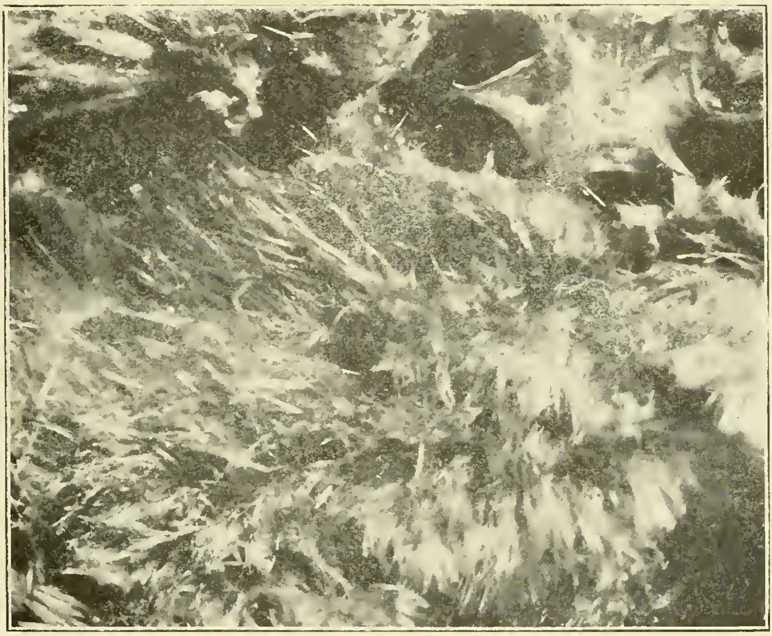

Plate XVII. Micro-photograph of ferro-aluminium sulphate collected from black clay by evaporation.

enough to draw away from the pan slightly, and fresh water was added to the clay in the pan, fresh sulphate was deposited in a film, stretching between the old deposit and the surface of the pan. The film consisted of a translucent convex layer of pearly luster with its surface covered with lines, like lines of growth, running longitudinally and transversely.

The sulphate which accumulates when the black clay from beneath the kaolin is placed in water seems in its physical properties to correspond to some of the varieties of halotrichite, though it may be only a mixture of melanterite and

alunogen. The accumulated sulphate may vary in composition with the abundance of melanterite and alunogen.

A sample of the sulphate was analyzed by Dr. R. E. Lyons with the following results: "The crushed material heated to 125°C sinters together and changed to chocolate-brown color. Dried at 145°C the mineral suffered a loss of 31.52% (expelled water). Not all of the water is expelled at 145°C. Ignited over a blast, the mineral suffered a loss of 75.61% (water and sulphur trioxide)."

ANALYSIS OF SULPHATE.

Found.	%.	Calculated.	%.
Ferric oxide (Fe_2O_3)	19.35	$FeSO_4$	38.70
Alumina (Al_2O_3)	5.73	$Al_2(SO_4)_3$	19.21
Sulphur trioxide (SO_3)	33.84	Free H_2SO_4	1.23
Water	41.08		
Total	100.00		

The mineral was formed and collected in the air and is lower in per cent. of alumina than halotrichite. It corresponds in composition more nearly to the mineral coquimbite when a part of its iron is replaced by aluminium. This mineral is a greenish or yellowish-white mineral which is soluble in cold water but which precipitates iron hydroxide when the solution is heated. The sulphate first collected from the black clay is readily soluble in cold water and does not precipitate iron hydroxide. After pyrite is added to the black clay in order to keep up the deposition of the sulphate the mineral deposited is soluble in cold water and precipitates iron hydroxide on heating.

In the presence of free oxygen the ferrous sulphate, $FeSO_4$, may be oxidized to ferric sulphate, $Fe_2(SO_4)_3$ as follows:

$$6FeSO_4+3O+3H_2O=2Fe_2(SO_4)_3+Fe_2(OH)_6.$$

Those portions of the black clay deposits deeply buried may contain iron only in the ferrous state and such compounds as halotrichite may be present. In the presence of free oxygen the ferric compound, coquimbite, might be formed.

Near the outside of the deposit the ferric sulphate, in the presence of water, might produce limonite as follows:

$$Fe_2(SO_4)_3+6H_2O=2Fe(OH)_3+3H_2SO_4.$$
$$4Fe(OH)_3=2Fe_2O_3+6H_2O=2Fe_2O_3+3H_2O+3H_2O.$$

Limonite is found underneath the white kaolin near the outcrop in the north Gardner mine.

The sulphur which is stored by the bacteria may be converted into sulphuric acid as follows:

$$2S+6Fe_2(SO_4)_3+8H_2O=12FeSO_4+8H_2SO_4.$$

This reaction could occur only where there was sufficient free oxygen for the oxidation of ferrous sulphate to ferric sulphate. Whether enough oxygen for this purpose would be set free by the bacteria in the reduction of carbon dioxide is doubtful. The sulphur might be converted into hydrogen sulphide and this oxidized to sulphuric acid.

It may be assumed that the amount of water present fluctuates. With abundance of water it is possible for the ferric sulphate to break up into ferrous sulphate, sulphuric acid and oxygen as follows:

$$Fe_2(SO_4)_3+H_2O=2FeSO_4+H_2SO_4+O.$$

Dark Colored Clay Beneath the Kaolin.—The clay which lies beneath the kaolin is bluish-black when wet and grayish-black when dry. (See Plate XVIII.) The gray color of the dry clay is due to the evaporation, bringing the soluble salts to the outer surface. In structure it is slightly laminated. The laminated appearance seems due to a change in color rather than to a material change in the size of grain or composition of the clay. The laminæ consist of light and dark bands. The light bands are not always continuous but are made up of lens-like masses with their longer axes in the same general plane. The clay when dried forms hard masses which do not show as many shrinkage cracks as ordinary clay. Generally speaking, there will be one or two large cracks to a mass of clay four inches in diameter. The streak of the clay is gray in color. The surface of the dry clay may be polished to a smooth shiny surface by rubbing the clay on an oilstone without the use of oil or water. The polished surface is black with white irregular particles, irregularly distributed on the smooth face. The specific gravity is 1.78.

Foreign Matter in the Black Clay.—An examination of the black clay underlying the kaolin revealed the presence of considerable foreign material. Both organic and inorganic substances were found.

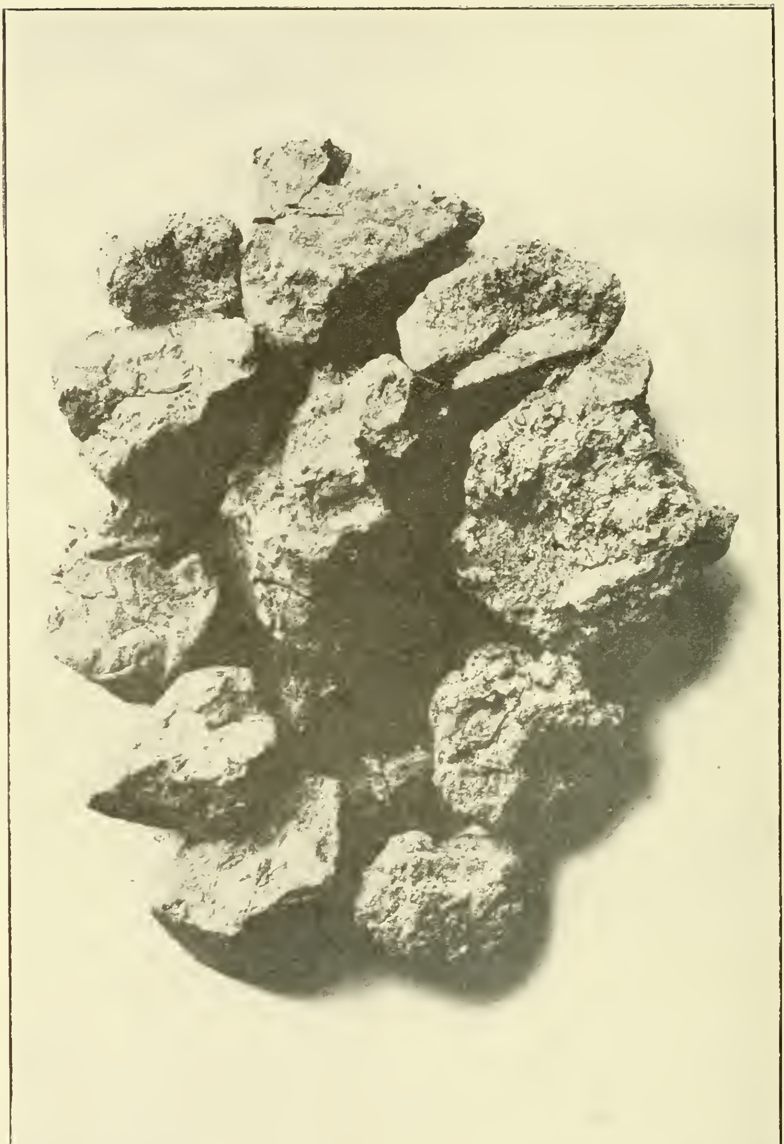

Plate XVIII. Black clay from beneath kaolin in Gardner mine. Rests on Elwren shale and contains pyrite and sulphur bacteria.

Quartz Pebbles.—The black clay contains pebbles of milk white quartz. (See Plate XIX.) The pebbles vary in size from that of a pea to that of a plum pit. The surface of some of the pebbles is etched and corroded, and they are more brittle than the pebbles in other parts of the Mansfield. There seems to be quite a marked difference between the pebbles from the black clay and the pebbles contained in the Mansfield sandstone which has not been penetrated by solutions from the black clay. The pebbles in size, shape and composition resemble those in the Mansfield sandstone which lies above the black clay. Since no pebbles have been found in the Mississippian, it seems evident that the black clay belongs to the Pennsylvanian, but the shale below the black clay is undoubtedly of Mississippian age, since it contains the same characteristics as the Elwren shale which lies between beds of Mississippian limestone in the same stratigraphical horizon both north and south of this point.

Marcasite Concretions.—Irregular concretions of marcasite were found in the clay. They are generally elongate bodies, some are kidney-shaped and some in the form of spherical bodies of small size. All of the concretions exhibit evidence of decomposition. (See Fig. B, Plate XIX.)

Mica.—Small flakes of mica of the muscovite variety appear in some layers of the clay but the quantity is small and is not greater than that usually found in the Chester shales.

Organic Matter.—The organic material found in the black clay underlying the kaolin, besides the bacteria, includes lignitic material which is usually in a very finely divided state. This organic matter is probably responsible for the dark color of the clay.

White Clay.—Small masses of white clay also occur in masses of black clay. These are generally spherical in form and plastic. As seen under the microscope, the spherical masses are composed of granules. It is difficult to separate the spherical particles of white clay completely from the dark clay matrix. The composition of a number of these white particles, separated as completely as possible from the matrix, is as follows:

Plate XIX. Fig. A—Quartz pebbles from black clay. Note etched and corroded surfaces.

Plate XIX. Fig. B—Nodules of marcasite from black clay beneath kaolin. Source of the sulphuric acid producing aluminium sulphate.

ANALYSIS OF WHITE CLAY BODIES.

	Per Cent.
Silica (SiO_2)	41.82
Ferric oxide (Fe_2O_3)	.29
Aluminium oxide (Al_2O_3)	32.65
Titanium oxide (TiO_2)	.04
Calcium oxide (CaO)	.40
Potash (K_2O)	.12
Soda (Na_2O)	trace
Sulphur trioxide (SO_3)	00.085
Loss of ignition	18.47
Total	93.875

White Quartz Sand.—A few thin layers of white quartz sand were found in the dark colored clay. Grains of white kaolin occur surrounding the sand grains. Two adjacent layers were examined, each about one-half inch thick. The upper layer contains only a small quantity of kaolin and a larger quantity of quartz sand. In the lower layer the conditions were reversed.

Ferro-Aluminium Sulphate.—When placed in water a soluble ferro-aluminium sulphate was derived from the black clay. This compound collected on the walls of the vessel about an inch above the surface of the water. Its behavior is different from alunogen, which may be produced by treating kaolin with sulphuric acid. The latter forms a white incrustation which gradually creeps over the edge of the containing vessel and falls off. The former is greenish-white in color, forms irregular globular bodies and does not advance beyond the edge of the vessel. It is readily soluble in cold water and may be precipitated by the addition of ammonium hydroxide.

Yellow Clay.—Not all of the under-clay is black in color. Some of it is yellow and resembles in structure the mahogany clay, but is much lighter, as though it had been bleached. The yellow clay seems to be an intermediate form between the black clay and the shale which lies below.

Bacteria.—The water surface above the clay, after it has been placed in water and allowed to settle, is clear and appears free from sediment or cloudiness of any kind. Later the surface of the water becomes covered with a white film which becomes thick and finally forms a dense white web-like mass, resembling snowflakes on the surface of a pond. The micro-

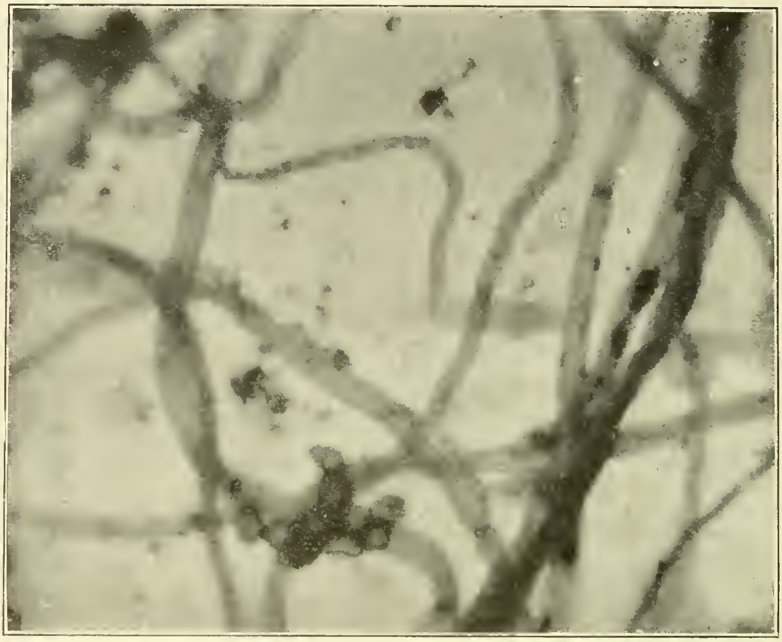

Plate XX. Fig. A—Sulphur bacteria taken from black clay beneath white kaolin. Enlarged 1,800 diameters. Mineral matter in cells and along filaments.

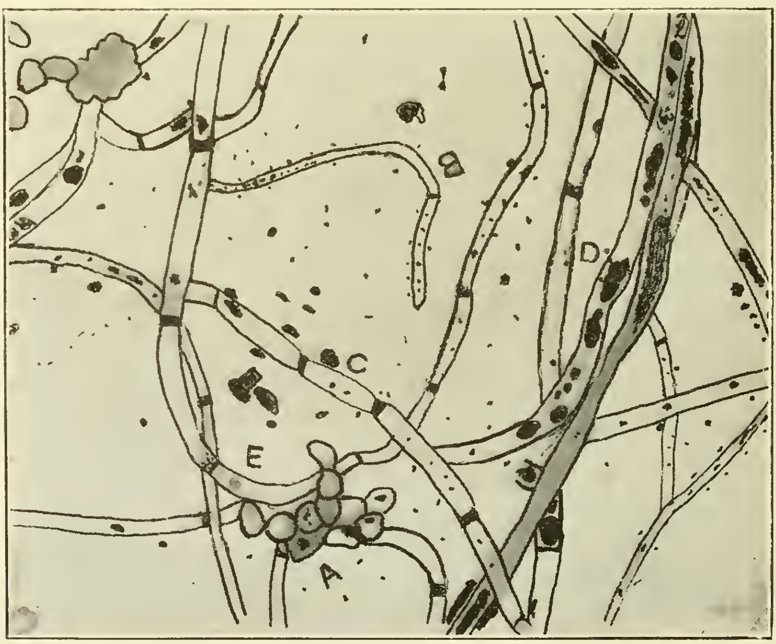

Plate XX. Fig. B—Same as above. Cells outlined. A. Spore cluster. B. Young filament. C. Older form. D. Mineral matter in cell. E. Sulphur? in cell.

scopic examination of these web-like bodies shows that they are made up of filaments and small minute, bead-like bodies. Along the side of these filaments there is a collection of mineral matter of a granular nature. Under a microscope of very high power these filaments are found to be made up of elongated cells. The small bead-like bodies are found to be very short, irregular cell-like bodies. These organic forms seem to be bacteria of some species closely related to species of the genus Beggiatoa. These bacteria are capable of living in a strong solution of sulphuric acid. (See Plate XX.)

The bacteria found associated with the black clay underlying the kaolin consist of thread-like filaments. These filaments vary in diameter from 2 to 3 microns. The filaments are segmented. The segments vary in length from 11 to 20 microns. The filaments cluster near the top of the water, forming first a white film and later a thick cotton-like mass. A small colony of bacteria presents the appearance of a pyramid or cone, the apex projecting down into the water and the base lying near the surface of the water, but the whole completely submerged. When separate colonies occur in the water they soon spread out and unite by their edges until the entire surface of the water is covered.

The Morphology of the Bacteria.—The filaments in their youthful stages are long and slender. They increase in diameter and separate into short segments. These shortened segments subdivide into elongate spore-like cells. Under the low power lens of the microscope these spores appear to be spherical and are arranged in rows which are often sixty or more microns in length. Under a lens of high power these spores are found to be elongated cells, having an average length of 2.8 microns and an average width of 1.5 microns. The shape is somewhat irregular but the ends of the longer diameter are somewhat constricted. When stained with methylene blue, the spores show the presence of small dark bodies within the walls of the spores. These bodies are distinctly irregular in size and number. Not all the spores contain these dark bodies. The filaments also contain what appears to be the same substance. The bodies, however, in the filaments are usually larger than those contained in the spores. These bacteria seem to be closely related to the sulphur bacteria of the genus Beggiatoa. These bacteria accumulate sulphur in their cells,

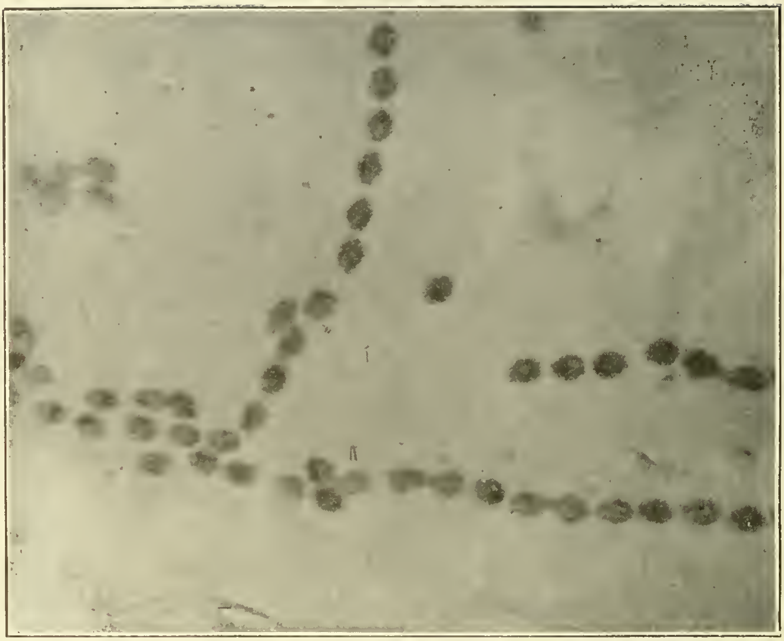

Plate XXI. Fig. A—Chains of spores. Enlarged 1,800 diameters. Dark spots mineral matter.

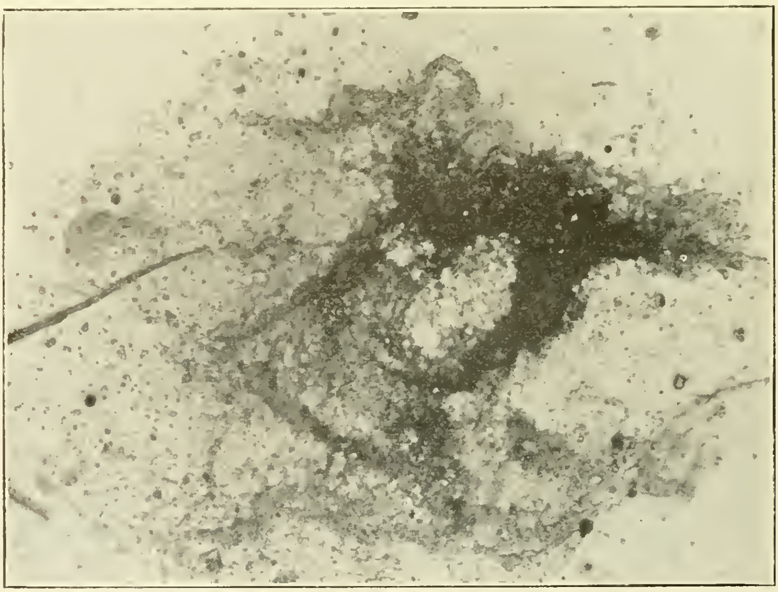

Plate XXI. Fig. B—Mass of bacteria and secreted mineral. Taken with lens of low power.

sulphur being derived from hydrogen sulphide. They also convert sulphur into sulphuric acid. They consist of cells without nucleus. The colorless cells are arranged in filaments. The filament has no sheath and is composed of plain rod shaped cells. The filaments move by an undulatory movement of the cell wall. They propagate by the separation of the filaments into segments, the shorter segments by further segmentation forming spores. The cells usually contain stored grains of sulphur. Nathan Zohn found sulphur bacteria which did not oxidize hydrogen sulphide but thio-sulphide and, therefrom, sulphuric acid. Unable to oxidize organic substance, they proclude no carbon dioxide and have no normal respiration. Carbon dioxide is a food-stuff and they form organic matter from it. They are organisms which respire inorganic material only.

Composition of the Under-Clay.—The dark colored underclay contains a high per cent. of silica, which is due in a large part to the presence of white quartz pebbles and sand. It also contains a high per cent. of volatile matter, due no doubt to the presence of pyrite and organic matter.

Acidity.—A solution obtained by placing black clay in distilled water is strongly acid. The presence of decomposing pyrite explains the cause and nature of the acidity. Treating the solution with barium chloride, a white precipitate was formed, which was insoluble in hydrochloric acid. This proves the acid to be sulphuric.

Sources of Sulphide of Iron.—The sulphide of iron is derived from the Chester shales. Some horizons of these shales contain large quantities of nodular and lens-like masses of sulphide of iron. A part of the sulphide of iron is obtained from the limestones which are embedded in the shales. The decomposition of the limestone sets free the sulphide of iron, which by oxidation forms sulphuric acid. The latter attacks the clay and forms the aluminium sulphate which is acted upon by the bacteria. Some of the limestones of the Chester contain large quantities of pyrite and there is no doubt of their influence in the formation of mahogany clay. Some of the pyrite was also derived from the organic matter deposited with the clay at the base of the Pennsylvanian and the Elwren and other sandstones of the Mississippian.

Bio-chemical Experiments.

Experiment I. Black clay from beneath the white kaolin was placed in a small deep pan and covered with water to the depth of one inch. The solution gave an acid reaction. After standing for awhile, sulphate collected on the edge of the pan. Later, a white film was formed on the surface of the water; this film increased in thickness until it formed a white cottony mass, covering the surface of the water. An examination of these cottony masses proved them to be colonies of

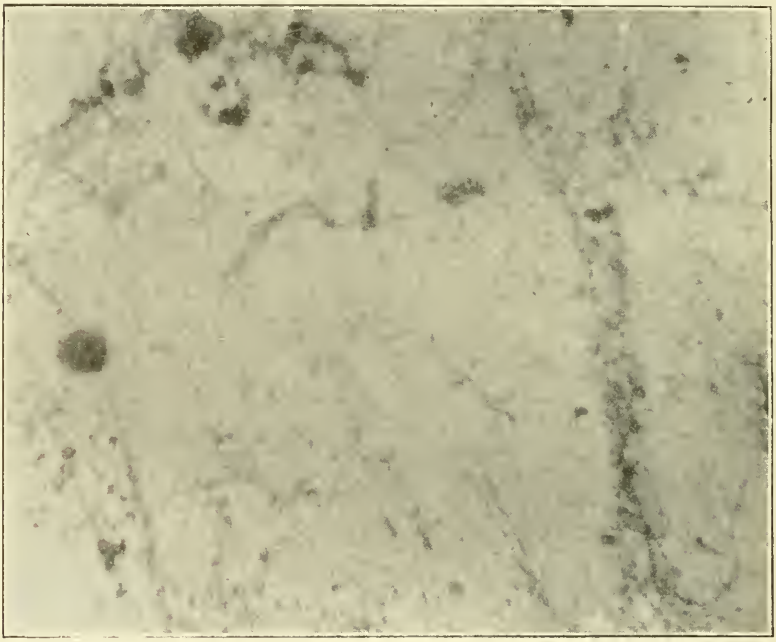

Plate XXII. Micro-photograph of floating mass of bacterial filaments with mineral matter along filaments.

bacteria, the meshes of their interlacing fibres containing granular and spherical bodies of mineral matter. The water evaporates and is renewed from time to time. Finally deposition halts, the surface of the water becomes covered with a film of oxide of iron. Some of this iron oxide is carried upward and deposits on the wall of the pan. The colonies of bacteria apparently disappear, but the spores are present in the water. Then a few drops of sulphuric acid are added to the water. The oxide of iron disappears, the water becomes clear, then the colonies of bacteria reappear. The mineral

matter found in the cottony masses of bacteria gives the reaction for alumina and silica and its granules are similar to those in the white plastic kaolin in the black clay and to those of the hard white kaolin. This kaolin is undoubtedly a secretion from the cells of the bacteria.

Experiment II. Some black clay from under the kaolin was placed in two test tubes and water was added to each. The solution formed was tested and found to be acid. After standing for a period of three days a small amount of sulphate was deposited on the walls of each test tube. More water was added to each test tube and a small colony of bacteria was placed on the surface of the water in one tube. After standing for one week the number of colonies of bacteria had multiplied, and the deposition of sulphate on the surface of the tube above the water had greatly increased. The uncolonized tube showed only a very slight deposit of sulphate. This experiment seems to afford evidence that the bacteria influenced the formation of the sulphate.

Experiment III. Black clay was placed into jelly glasses and covered with water. Both solutions gave an acid reaction. As the water evaporated a slight deposit of sulphate took place on the walls of the glass, above the water level. Deposition ceased after a few days and the water surfaces were covered with a film of iron oxide. No bacteria were present in either glass. To the water in one of the glasses a colony of bacteria was added; these multiplied in number and the sulphate increased on the walls of the glass. Later, a few drops of sulphuric acid were added and the bacteria showed a greater increase and the deposit of sulphate also increased.

Experiment with Black Clay.

Some of the black clay taken from beneath the white kaolin was placed in a shallow pan of enamelled ware; distilled water was added; in a few days a thin film covered the surface of the water. A portion of the film was examined under the microscope and found to be filamentous microorganisms, interlaced, and the meshes thus formed either partly or wholly filled with mineral matter. The mineral matter was present in the form of minute granules which were distributed along the walls of the filaments either in single granules or as clusters of granules.

A number of questions presented themselves. Was the mineral a secretion of the micro-organism? It did not take on the form of a crystal; it was granular like secreted masses; it was not present in the solution where the micro-organisms did not exist; it was present where even a single filament existed.

Could the mineral be precipitated by the evaporation of water from concentrated portions of the solution in the meshes formed by the filaments of the micro-organism? This did not seem to be a reasonable assumption since no precipitation was

Plate XXIII. Dense mass of bacteria with enmeshed mineral matter.

taking place along the sides of the vessel, which indicated that the solution was not very concentrated; and then there was the presence of the mineral where no meshes existed but only single filaments.

Was the mineral soluble? The solution was acid. Could a soluble mineral exist in it? It was suggested that it might be soluble but protected by an organic film but the sulphuric acid of the solution would soon break up an organic film. To determine whether the mineral was soluble and precipitated by evaporation of the water the pan was placed under a bell

Plate XXIV. Layer of coarse conglomeratic sandstone between layers of white kaolin in Gardner mine. Grains cemented with kaolin.

jar and evaporation prevented, but the mineral continued to form, proving that it was not the result of evaporation. The filaments were washed in water and dilute acids without removing the mineral. Collections of the micro-organisms and the associated mineral matter were dessicated and gave reactions for alumina and silica. After a period of time granules dropped from the meshes of the filaments to the surface of the clay beneath the water. It was easily distinguished from the clay as it was light and moved back and forth with the movement of the water. Under the microscope it appeared like the grains in the meshes of the filaments. It took stains in a similar way. The mineral matter in the interior of the bacterial cells was similar in appearance and staining to that along the exterior walls of the cells.

In order to determine the chemical composition of the secretion of the bacteria some of the black clay was placed in a vessel containing water. The vessel was placed under a bell jar. The water above the clay was clear but acidic. After a few days a bacterial growth covered the surface of the water and mineral matter collected among the filaments. The bacteria and enmeshed mineral matter were collected from the surface of the water. The collected mass was analyzed by Professor R. E. Lyons. He first dried the mass at 100° and then for several days over $CaCl_2$ and H_2SO_4. He then found the dessicated mass to contain:

Silica (SiO_2)	17.34
Alumina (Al_2O_3)	21.56
Ferric oxide (Fe_2O_3)	3.38

The composition of the mass differs from the composition of kaolin, which is to be expected. In the first place, it must be borne in mind that the mass is not a single mineral but contains kaolin, aluminium sulphate and ferrous sulphate.

Therefore, when the volatile matter is driven off the residue is found to be composed of sufficient silica to form about 42.78% of kaolin; an excess of alumina, which is probably derived from the aluminium sulphate, and 3.38% of ferric oxide, which was derived mainly from the ferrous sulphate. Since the kaolin is secreted into a solution of aluminium sulphate and ferrous sulphate which has a leaching action upon it before it is collected, and since some of this solution is collected with it we should not expect this collected matter to

have the same composition as pure kaolin. However, in the presence of sand or other forms of silica it would be converted into kaolin, since the excess of free alumina would unite with the silica, and this is what probably occurs when the bacteria

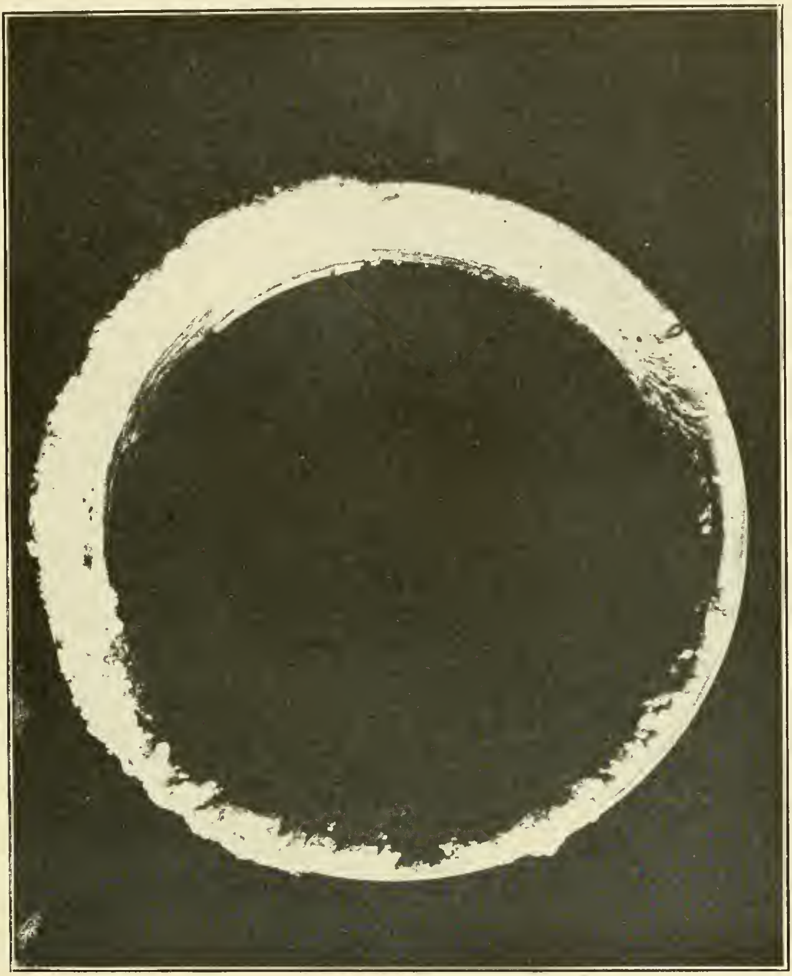

Plate XXV. Aluminium sulphate (Alunogen) collecting on walls of pan and falling over edges. Alunogen formed by treating kaolin with sulphuric acid.

are in actual contact with the sand or quartz pebbles in the clay.

It is immaterial whether the alumina unites with the silica within the cells of the micro-organism or unites with it after its secretion. That the union takes place within the cells is

probable, because the mineral matter within the cells reacts to stains like that on the outside, its appearance is similar, its solubility is similar, and the silica being soluble, could enter the cells as freely as the aluminium sulphate. The mineral matter within the cells to be visible would of necessity be an insoluble compound.

Experiment with Knobstone Shale.

A sample of aluminous Knobstone shale was selected from an outcrop on the I. C. railroad, east of Bloomington. This shale contained considerable pyrite which was partly decomposed. When the shale was placed in water in a vessel, it gave a strong acid reaction. A colony of bacteria was placed on the surface of the water. In the course of a few days the surface of the water became covered with the bacteria and the secreted mineral matter. Before the bacteria were placed in the solution there was a slight precipitation of sulphates around the margin of the vessel as the water was evaporated. The amount of precipitation increased noticeably with the addition of the bacteria.

Experiment with Chester Shale.

A sample of Elwren shale was placed in a vessel and water and fragments of pyrite were added. In the course of a few weeks ferro-aluminium sulphate collected on the walls of the vessel in small quantities. After standing for three months, the water being renewed from time to time, no evidence of white kaolin was found in the shale.

In a second vessel an equal amount of the same shale was placed, covered with water and pyrite added as before. At the end of a few weeks, when the sulphates began to appear, a colony of bacteria was placed on the surface of the water. In the course of two weeks the bacteria covered the surface of the water and mineral matter was collected in the meshes of the filaments and in a few weeks was dropping down to the surface of clay.

Conditions of Accumulation of Kaolin.—It is assumed that shale or clay, quartz pebbles and organic matter were deposited in a shallow basin and sand deposited above them. During the decomposition of the organic matter, pyrite is formed. Later deposition was followed by elevation; erosion

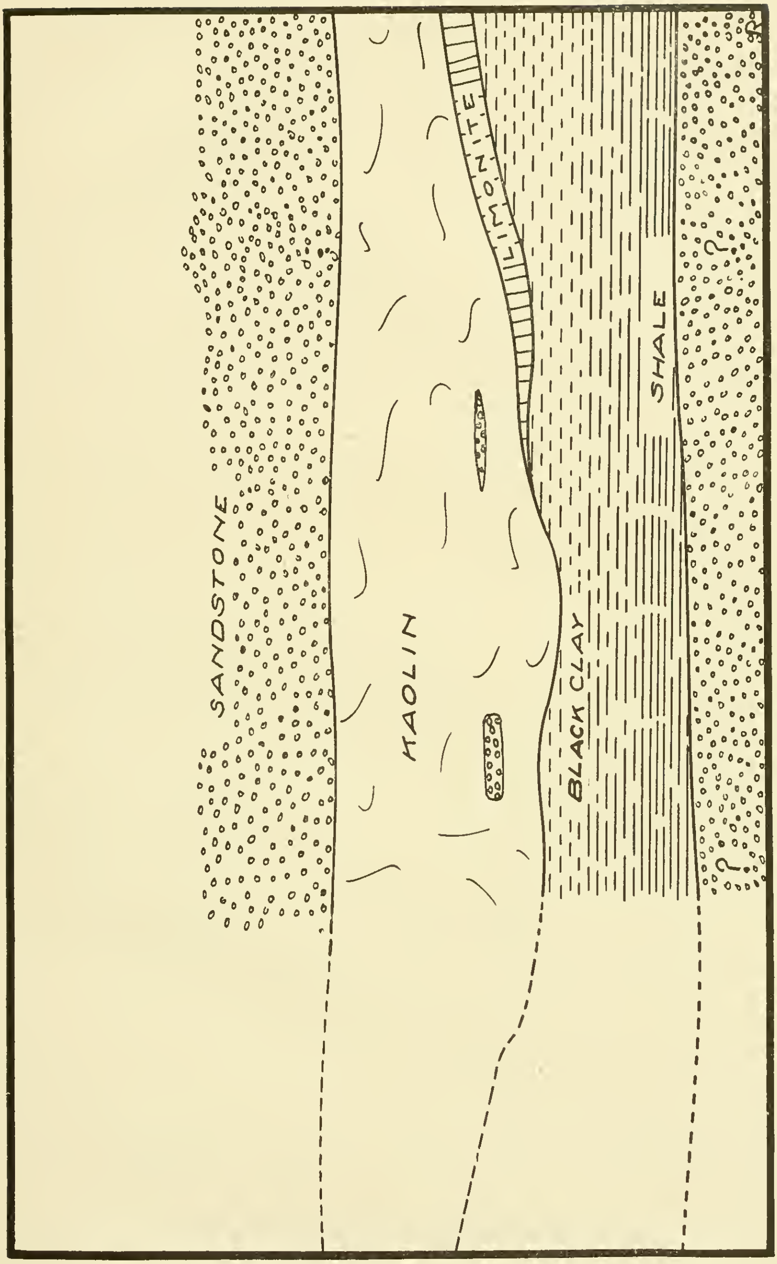

Plate XXVI. Fig. A—Diagram showing sandstone layers in kaolin. Limonite layer below at one point, black clay at another. Gardner mine.

followed. The edge of the basin was uncovered, but its position was such as to collect the water which percolated through the overlying beds. (See Plate XXVI.) The lower portion of the filled basin thereby became saturated with water. The water, carrying oxygen, caused the decomposition of the pyrite, thus forming sulphuric acid and ferrous sulphate. The sulphuric acid attacks the clay and forms aluminium sulphate. Bacteria penetrated the basin. The micro-organisms can live without light or oxygen, so they continue to thrive in the pores of this saturated deposit. They absorb the ferrous sulphate and aluminium sulphate and secrete kaolin and possibly ferro-aluminium sulphate (halotrichite). In the presence of abundant water the sulphate passes upward into the bed of sand and acting on the sand grains, replaced them with kaolin. It has been demonstrated that the sulphate will do this by the experiments already described. After the deposition of the layer of kaolin near the top of the sand, deposition would not be checked, because the porous nature of the kaolin would permit the solution to continue to come through the lower layers of the sandstone, thus a thickness of many feet might be formed. The solution might remove most of the silica from the sand and, if the layer of sand were thin, it is conceivable that it might disappear entirely. As the amount of clay under the sand decreases, it is possible for the sand or sandstone to settle down. The movement being differential, the sandstone may be broken up into blocks. The sand in some of these blocks may be dissolved by the acid solution and the spaces thus formed filled with kaolin. This process would explain the occurrence of irregular sandstone blocks which are sometimes found in the beds of kaolin. No caving of the sandstone would take place since only a small area would be affected at one time.

Part Played by the Bacteria.—The influence of the bacteria in the formation of Indianaite seems to be positive. They seem to secrete kaolin and their presence seems to be essential to the formation of large quantities of the ferro-aluminium sulphate which attacks the silica so readily. They may also assist in conserving the supply of sulphur which is so essential to continuous formation of aluminium sulphate. There does not appear to be enough pyrite in the shales or in the limestones to supply the necessary amount of sulphuric acid

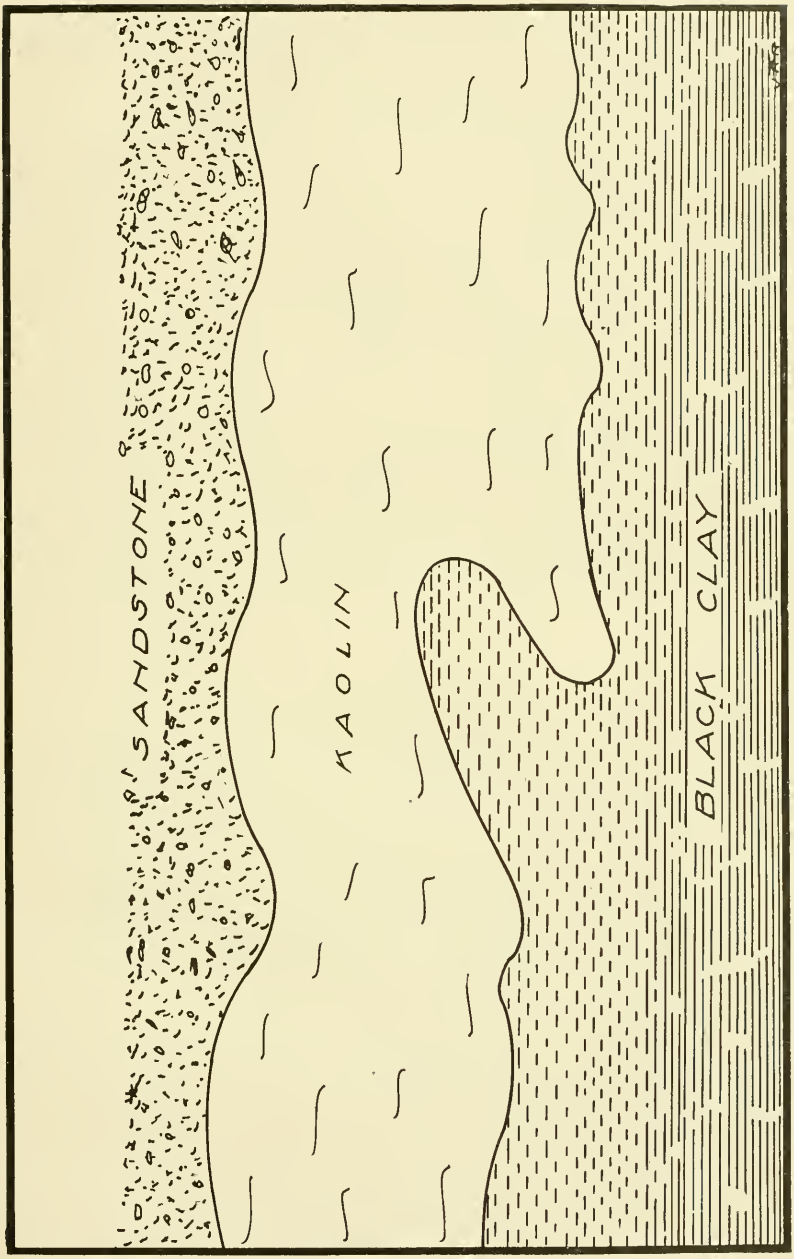

Plate XXVI. Fig. B—Diagram showing contact of black clay with kaolin in Gardner mine. At one point neck of clay extends into kaolin.

Plate XXVII. Fig. A—Micro-photograph of a thin section of limestone found in mahogany clay.

Plate XXVII. Fig. B—Showing contact of white kaolin and black clay, the latter partly converted into kaolin.

unless the supply is carefully conserved. The sulphur which the bacteria take from the ferrous sulphates would ultimately be converted into sulphuric acid. The latter would attack the clay and a clay-sulphuric acid-alum-bacteria-sulphuric acid cycle would be established. Such a cycle I believe to be essential to the formation of large quantities of kaolin. The amount of pyrite might be small since by the action of the bacteria only a small amount of the sulphur would be lost. By the reduction of the sulphates by the bacteria some oxygen may be set free for the further oxidation of the pyrite or the precipitation of the iron compound. A layer of very pure limonite is sometimes found beneath the kaolin. The bacteria may take part in the formation of colloidal kaolin which is found in the black clay. It seems probable, too, that the granules of plastic white kaolin occurring in the kaolin are secreted by the bacteria. They are composed of rounded grains resembling the oölites of algæ secretions. In the case of lime-secreting algæ "the lime is enclosed in the alga-body in the form of rounded tubercles, which often gather themselves together into larger irregular tubercular bodies." (Rothpletz.)

The similarity of the microscopic grains found within the cells of the bacteria and along the outside walls of the cells to the grains in the soft white kaolin and those in the hard white kaolin is remarkable. A microscopic examination of the filaments of the bacteria reveals the presence of mineral which is insoluble in water entangled in the meshes of the bacterial filaments and distributed along the outside walls of the cells. This compound gives reactions for alumina and silica and contains water of crystallization. Physically, the mineral is made up of tubercles and these are collected into larger masses. These tubercles are similar in size and appearance to those found in the soft plastic kaolin of the black clay and to the granules of the hard white kaolin. They are also similar in appearance and react to stains in the same way as the larger bodies in the cell walls of the bacteria.

It appears that there are here two methods of kaolinization; that in the presence of only a small amount of water the clay or shale is changed in situ by bacterial elaboration, the kaolinization extending downward; that when there is an abundance of water present the soluble ferro-aluminium sulphate is carried upward into beds of sandstone where it is con-

verted into kaolin, a replacement process producing an upward extension of the kaolin deposit.

The conditions for the formation of kaolin by the bio-chemical process are too complex to be met frequently. If the process involved only the decomposition of pyrite in connection with shale, kaolin deposits would be found in most areas of sedimentary rocks because the decomposition of pyrite in shales is of common occurrence. But the conditions for kaolinization demand more than the presence of decomposing pyrite in shale, the essential conditions for the growth of bacteria must be present. There must be present also conditions favorable to the accumulation of kaolin. The ensemble of essential conditions is of rarer occurrence.

Since the activities of micro-organisms are controlled by temperature, the matter of climate enters into the problem. Since sulphur bacteria have been found to be active in the latitude of southern Indiana in the kaolinization process at the present time, are we to infer that the climate of this latitude is to be taken as the favorable one for their activities? If the climatic factor is an important one, it might be assumed that if the southern kaolins were formed by bacterial action, that a climate similar to the present climate of southern Indiana must have prevailed in that region some time subsequent to the deposition of the Tuscaloosa and the other formations bearing kaolin. Such climatic condition must have prevailed about the time of the glacial period if not earlier.

The optimum temperature of sulphur bacteria is probably not far from 50° F., since this would be about the uniform temperature of a bog deposit in this latitude and is about the average temperature of the clay at the point where the bacteria were collected.

The question may be asked: Why are not such deposits of kaolin of more widespread distribution? In the first place kaolin deposits of like origin may be more widely distributed than Indianaite. The Tuscaloosa, the Wilcox and the Lafayette formations of the south contain kaolins and white clays that may have a similar origin. These kaolins occur in sedimentary rocks associated with sands and often at great distances from feldspathic rocks. All of these formations contain organic matter in the form of beds of lignite containing pyrite. The composition of samples of kaolin collected by the

writer from the Tuscaloosa formation in Mississippi is given in the following table:[1]

ANALYSIS OF TUSCALOOSA KAOLIN FROM MISSISSIPPI.

	No. 1.	No. 2.	No. 3.	No. 4.
Moisture (H_2O)	00.87	.48	1.11	....
Volatile matter (CO_2etc.)	11.96	15.01	13.88	15.17
Silicon dioxide (SiO_2)	38.11	44.23	42.92	44.75
Iron oxide (Fe_2O_3)	11.73	.81	.61	.95
Aluminium oxide (Al_2O_3)	36.42	38.82	41.30	38.39
Calcium oxide (CaO)	0.60	.19	.37	.37
Sulphur trioxide (SO_3)	tr.	.45	.18	alk. .35
Magnesium oxide (MgO)	.14	.13	.13	.30
Total	99.82	100.12	100.57	100.28

No. 4 is the analysis of a sample of Indianaite made by W. A. Noyes and placed here for comparison.

The presence of such beds of pure white kaolin in sedimentary formations has long been an enigma and a source of speculation to the writer. There appears to the writer no inconsistencies with the view that these southern kaolins may have originated in the same way as the Indianaite. The chemical compositions are similar and the physical properties of certain portions of each are similar.

Origin of Mahogany Clay.

The mahogany clay is found occasionally in connection with limestones occurring in contact with shale. The shale is a highly aluminous formation. The origin of the mahogany clay seems to be in some way connected with the decomposition of the limestone. The bowlder-like masses of limestone are very frequently found in the shales surrounded by mahogany clay. In some of these masses of clay fragments of white kaolin are found. The aluminous shale is decomposed along with the decomposition of the limestone. In some places the limestone contains large quantities of pyrite. In many places the shale also contains pyrite. In the decomposition of pyrite, sulphate of iron and sulphuric acid are formed. The oxidation of the sulphate of iron produces oxides of iron, which give to the mahogany clay its reddish color. The sulphuric acid attacks the aluminium silicate of the clay and forms

[1] Logan Clays of Mississippi, Miss. Geol. Survey, pp. 2 loc. cit.

aluminium sulphate. This aluminium sulphate is converted into kaolin by the action of the sulphur bacteria. During the decomposition of the limestone some calcium sulphate is formed. Crystals of the crystalline form of gypsum selenite are formed in the shale at points near the mahogany clay.

The first change due to weathering is from an olive-green shale to a maroon colored clay, which is very plastic. The maroon clay is changed into the mahogany clay which is less tenacious, and in some outcrops not very plastic.

The mahogany clay is in some instances formed by the staining of beds of white kaolin with iron oxides and by the partial disintegration of the kaolin. This may occur where the sandstone roof above the kaolin has been partly removed so that quantities of surface water may penetrate the bed of kaolin.

Chapter V.

USES OF INDIANA KAOLIN.

The kaolin of Lawrence and adjoining counties is suitable for use in a number of industries in some of which its value is already well established. Its utilization in quantity has been in the ceramic industry and in the manufacture of aluminium sulphate. The kaolin of Lawrence County was used for many years in the manufacture of this mineral, but cryolite supplanted it and was in turn supplanted by bauxite. Economy of production seems to have been the influencing factor in each substitution.

Alum Cake.—The kaolin from Dr. Gardner's place in Lawrence County was used for many years in the manufacture of aluminium sulphate. It is readily soluble in dilute sulphuric acid and is said to be superior to other aluminium silicates for this purpose. Large quantities of alum cake are now used to produce flocculation of clay particles in water intended for domestic use. With an abundance of pyrite for the manufacture of sulphuric acid there is no reason why alum cake should not be manufactured with profit in Indiana.

At the request of the writer, Mr. Jacob Papish offers the following suggestions as to the method of treatment of kaolin in the manufacture of alum cake:

"The plant to be erected for the treatment of kaolin is to consist of a series of tanks, the latter being rectangular or round in shape built of 2 x 4 inch lumber and lined with 9 pound lead. A convenient size for a tank is 20 x 18 x 6 feet, which is suitable for the treatment of half a carload of kaolin at one time. The boiler and engine should be of a larger capacity than the immediate requirements, so as to take care of future expansion. On the other hand, in order to have the immediate returns as large as possible, it is advisable to procure a cheap kerosene engine. Such an engine will take care of a battery of two tanks at a time, and since stirring and mixing are not a continuous operation with a given batch of material, a cheaper engine would be satisfactory. The cost of erection of one tank and the price of the required accessories are given in the following table:

Tank, 20 x 18 x 6	$300 00
Lead lining (9-pound lead)	403 00
Stirrer, lined with lead and shaft	60 00
Belting, pump, spouts, etc	100 00
Kerosene engine which can be used in connection with several tanks	100 00
Total	$963 00

"The method of treatment, in the main, is as follows: The kaolin should be allowed to weather so as to crumble to pieces. Fifteen tons of this material is to be introduced in a tank and an equal quantity of sulphuric acid added with constant stirring. The stirring should be continued for several hours. After a period of two or three days the cake is ready for shipment. The heat of the reaction is sufficient to remove the surplus water. With proper management, one tank can be made to throw out 90 tons of alum cake in a week, and for one year of 50 weeks this means a production of 4,500 tons.

COST OF PRODUCTION OF 450 TONS OF ALUM CAKE. (Crude.)

225 tons of kaolin ($4 per ton)	$900 00
225 tons of sulphuric acid (60°, $16 per ton)	3,600 00
Taxes, insurance (10%)	96 00
Overhead charges, depreciation of plant (20%)	192 00
Labor (20% of selling price)	2,250 00
Total	$7,038 00

"It is seen from the above that the cost of production of one ton of alum cake is $15.64.

"Some municipal water works in Indiana are buying crude aluminium sulphate at $45 per ton. Making an allowance for the difference in active material, the alum cake prepared from kaolin should sell for $25 per ton. The margin of profit offers an excellent inducement to the manufacturer. I remember that you made the statement last year that the manufacture of alum cake from kaolin is a paying proposition. Having gone over the different cost data, I am ready to confirm your statement. The main question is the market. The overhead charges and the cost of labor given in my estimate will take care of cost of delivery to railroad cars."

Pottery.—The purer varieties of kaolin may be used in the manufacture of white wares. Such wares are manufactured

out of a mixture of feldspar, kaolin, quartz and ball clay. Kaolin to be used for this purpose must be very low in percentage of iron to prevent coloring of the ware. The materials used in the manufacture of white ware are reduced to the powdered form, put into a blunger and water added, the portion of each being weighed in order to keep the right proportion in the mixture. After being agitated in the blunger from an hour to an hour and a half, the mixture is put through a sieve, thence through a trough to a vat. In the trough it comes in contact with magnets which remove particles of iron which may have been entered from the grinding machinery. In the vat the mixture is agitated until pumped into the filter press. The leaves of the mixture from the filter press are mellowed and pugged. From the pug mill the clay is taken to the molding room. After being wedged the clay is molded by throwing, jollying or jiggering, pressing or casting. The ware is then finished and fired in the biscuit kiln. It is then brushed, glazed and fired in the glost kiln.

Kaolin is used in the manufacture of the various grades of domestic white ware, sanitary ware, electrical ware and porcelain.

Refractories.—Kaolin may be used in the manufacture of refractories such as fire brick, fire proofings, furnace linings, glass pots, saggers and pottery kiln supplies. Since the Indiana kaolin is non-plastic it must be mixed with a plastic clay of high refractoriness in order to meet the requirements of these materials. Indiana possesses fire clays that are plastic and of such a degree of refractoriness as to serve very well as bonding material for kaolin in the manufacture of refractories as the following tests demonstrate:

Results of Kaolin-Fire Clay Tests.

In order to determine the value as a refractory of mixtures of Indiana kaolin and fire clays, these substances were ground, molded into cones and briquettes. The cones and briquettes were marked for the determination of shrinkage. After drying in the air the air shrinkage and loss of water were determined. The test-pieces dried without cracking.

Firing.—The cones and briquettes were then dried at 100°C until the weight remained constant. They were then placed in the kiln, the temperature of which was raised to that

recorded by the incipient fusion of Cone 30. The results obtained are recorded in the following table:

No. of Fire Clay	Per Cent of Kaolin	Wet Weight of Cones	Air Dry Weight	Air Shrinkage	Weight Burned Grams	Fire Shrinkage	Absorption.	Fired at Cone
18	25	57	44	.04	37	.08	0	30
18	25	46	36	0	30	.12	0	30
18	33⅓	37	29	0	25	.18	.16	30
18	33⅓	46	30	0	32.5	.16	0	30
18	50	49	37	0	30	.14	.066	30
18	50	53	41	0	33	.16	.062	30
20	25	47	36	0	32	.12	0	20
20	25	56	43	04	40	.12	.027	30
20	33⅓	63	48	0	40	.18	.05	30
20	33⅓	51	39	.016	32	.08	.031	30
20	50	60	46	.04	37	.08	.07	30
20	50	43	33	0	27	.08	.111	30
21	25	60	45.5	04	....	....	.11	30
21	25	44	33	.016	28	.06	0	30
21	33⅓	41	32	0	26	.16	.11	30
21	33⅓	34	27	.016	22	.06	.045	30
21	50	60	46	04	37	.08	.08	30
21	50	36	28	.04	23	.12	.30	30
22	25	46	37.5	04	32.5	.12	0	30
22	25	37	29	.10	25	.10	.04	30
22	33⅓	40	28	.06	23	.12	.043	30
22	50	43	29	.08	25	20	.04	30
22	50	44	30	.04	25	12	.08	30
22	50	43	29	.08	25	.20	.04	30
23	25	48	38	.04	33	.12	.03	30
23	25	52	41	.04	36	.08	0	30
23	33⅓	42	32	.015	27	.06	.073	30
23	33⅓	36	27	.02	23	.12	.043	30
23	50	50	38	0	32	.08	.12	30
23	50	52	40	.016	33	.10	.15	30

*Fire Clays from Clay County, Indiana.

Refractory Mixtures.—In order to determine the value of Indiana kaolin, Chester shales, mahogany clays and fire clays as refractory material mixtures were prepared, molded and fired.

Mode of Preparation.—The clays and kaolin were ground separately to pass a screen of 100 meshes to the inch, mixed in proportion by weight of air-dried clay, water added and

the mixture molded into cones and briquettes. The cones and briquettes were marked, weighed, and the weight marked on each. After drying in the air the loss of water and the air shrinkage was determined.

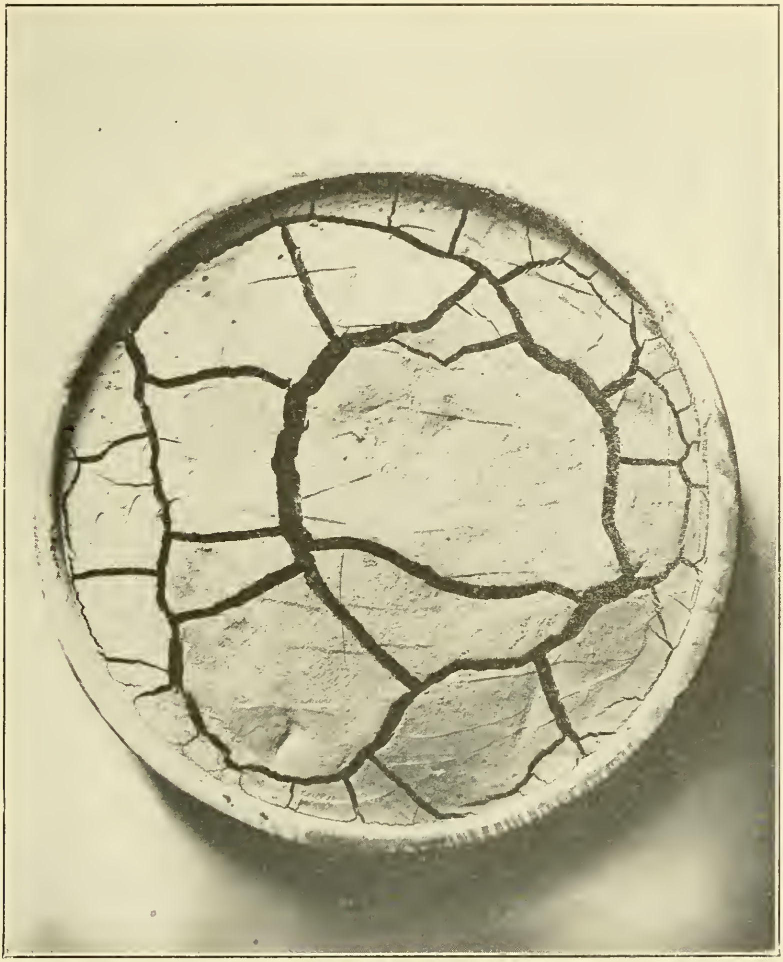

Plate XLV. Chester shale puddled and air-dried. Compare with mahogany clay in Plate XLVI.

Firing.—The cones and briquettes were then dried at 100°C until the weight remained constant. They were then placed in the kiln, the temperature of which was raised to that recorded by Cone 30. The results obtained follow the location of the samples.

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Mahogany Clay.

1. Near Landreth, Orange County, Orangeville Township.
2. Pearson Place, Lawrence County, Sec. 30, Twp. 4 N., R. 2 W.

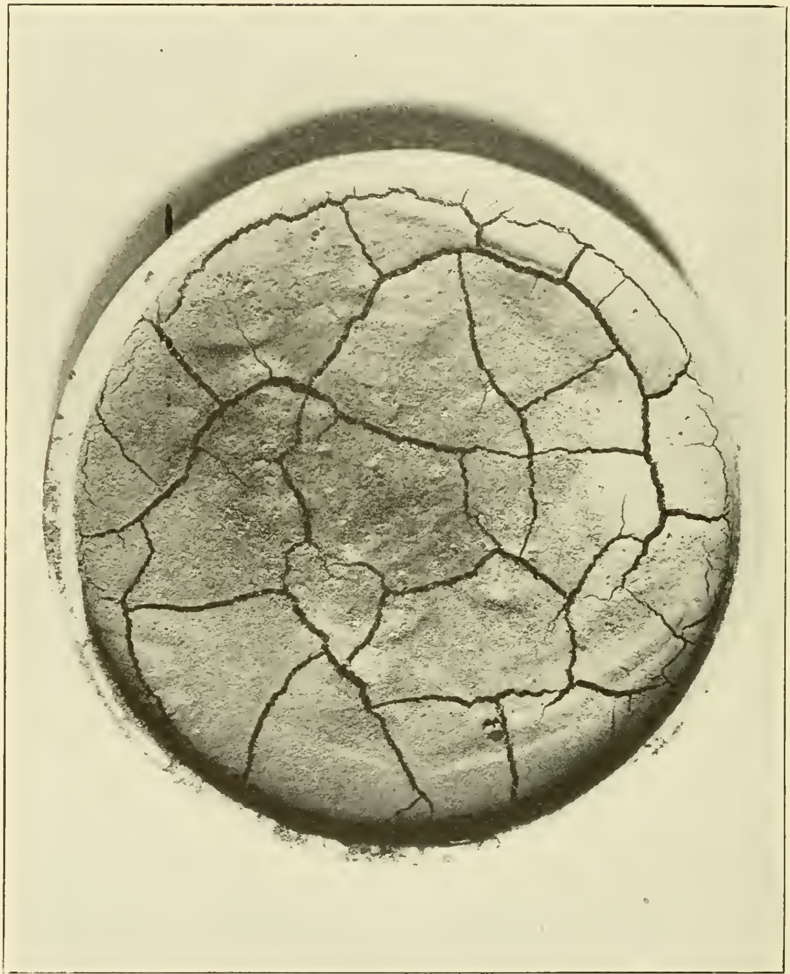

Plate XLVI. Mahogany clay which has been puddled and air-dried. Compare shrinkage cracks with those of the Chester shale. Plate XLV.

3. Wilson Place, Lawrence County, Sec. 8, Twp. 3 N., R. 2 W.
4. Hall Option Place, Monroe County, Twp. 7 N., R. 2 W., Sec. 10.

5. Purlee Place, Orange County, Orangeville Township, Sec. 2.

6. Timberlake Mine, Monroe County, Sec. 28, Twp. 7 N., R. 2 W.

7. Mr. Bridges, S. W. of Fortners, Martin County, Halbert Township, Sec. 2.

8. Below Paff house, Monroe County, Sec. 33, Twp. 8 N., R. 2 W.

9. Gardner Place, 2½ miles S. E. of Jones house, Lawrence County, Sec. 34, Twp. 4 N., R. 2 W.

10. South of Landreth House, Lawrence County, Sec. 18, Twp. 3 N., R. 1 W.

58. West of Monon Church, Hendersonville.

59. Edwards, Lawrence County, Sec. 28, Twp. 4 N., R. 2 W.

SHALES.

11. From Huron, Lawrence County, Twp. 3 N., R. 2 W., Sec. 5.

12. Near Gardner House, Lawrence County, Twp. 4 N., R. 2 W., Sec. 21.

13. Near Miller Hill, Lawrence County, Twp. 4 N., R. 2 W., Sec. 21.

14. Wilson Place, Lawrence County, Sec. 8, Twp. 3 N., R. 2 W.

15. Miller Hill, Lawrence County, Sec. 31, Twp. 4 N., R. 2 W.

16. Just below Cross Cave where dam washed out, Sec. 21, Twp. 4 N., R. 2 W.

17. One-half mile east of French Lick below Spring, top of mountain, Orange County, French Lick Township.

18. Pilot Knob, above 5 L. S., near Marengo, Crawford County.

19. West end of tunnel, west of Marengo, just above L. S., Crawford County.

20. Lloyd Place, Shoals, Martin County.

21. East of tunnel, west of Marengo, just below first L. S., Crawford County.

22. R. R. cut east of Huron, below first L. S., Lawrence County, Sec. 5, Twp. 3 N., R. 2 W.

23. Isaac Fortner Place, Huron, 50 feet above L. S., Martin County, Hulbert Township.

24. East of tunnel, west of English, below L. S., Crawford County.

25. West of English, near tunnel just below coal measure, Crawford County.

26. South of French Lick, below 3rd L. S., Orange County.

27. 1½ miles east of French Lick, below S. S. below L. S., Orange County.

28. East of West Fork, above 3rd L. S., Crawford County.

29. One mile south of Grantsburgh, just below 2nd L. S., Crawford County.

30. Miller Hill, Huron, Lawrence County, Sec. 21, Twp. 4, N. R. 2 W.

31. Ballard and Clayton farm, 2 miles S. W. of French Lick, red shale, Orange County.

32. Just east of West Forks, above 1st L. S.

33. Sandy layer below mahogany, Timberlake Mine, Monroe County, Sec. 10.

34. 1 mile west of English, below 1st L. S., Crawford County.

35. West of English, below 4th L. S., Crawford County.

36. North of Miftlin, just above 2nd L. S., Crawford County.

37. 1½ miles N. E. of Miftlin, just above 4th L. S., Crawford County.

38. 1st R. R. cut west of English, just above L. S., Crawford County.

39. One-half mile west of West Forks, above 3rd L. S., Crawford County.

40. Timberlake Mine, Monroe County, Sec. 28, Twp. 8 N., R. 2 W.

41. 1 mile west of English, just above 2nd L. S., Crawford County.

42. R. R. cut east of Huron, between 1st and 2nd L. S., Lawrence County, Sec. 5, Twp. 3 N., R. 2 W.

43. East of Huron, under 2nd L. S., Lawrence County, Sec. 5, Twp. 3 N., R. 2 W.

44. 1½ miles N. E. of Sulphur, just below 4th L. S., Crawford County.

45. N. E. of Huron, Lawrence Co., Sec. 32, Twp. 3 N., R. 2 W.

46. Fortner Place in Branch, Martin County, Hulbert Township.

49. 2 miles east of French Lick, Geo. Giles Place, below L. S., Orange County.

50. N. E. of Thrasher School House, Monroe County, Sec. 3, Twp. 7 N., R. 2 W.

51. Shoals, by Fred Jones', Martin County.

52. Shoals, Lloyd Place, just below coal, Martin County.

53. Huron Cut, Lawrence Co., Sec. 5, Twp. 3 N., R. 2 W.

54. Gardner Place, 2 miles east of Gardner House, just below mahogany, Lawrence County, Sec. 21, Twp. 4 N., R. 2 W.

55. 1st cut S. W. of French Lick, just below 1st L. S., Orange County.

56. Shale, Gardner Place, south of house, Lawrence County, Sec. 21, Twp. 4 N., R. 2 W.

57. Toward Nail Hill, east of Gardner House, Lawrence County, Sec. 22, Twp. 4 N., R. 2 W.

MIXTURE OF KAOLIN AND PUTNAM FIRE CLAY, STATE FARM.

1.	$\frac{1}{3}$ K.	$\frac{1}{2}$ K.	$\frac{1}{4}$ K.	$\frac{3}{4}$ K.
11.	$\frac{1}{2}$ K.	$\frac{1}{3}$ K.	$\frac{1}{4}$ K.	

1. White Kaolin was used.
11. Mine run Kaolin was used.

Results of Shale and Mahogany Tests.

The mahoganies and shales of these tests were treated alike. The material was ground and put through the sixty-mesh screen. Each clay was then molded into two pyramids of about thirty-four grams of weight, the weight was carefully put on them, they were numbered, and a depression exactly an inch long put in by means of a little paddle. These pyramids were allowed to dry in the air for about two weeks. After they were thoroughly air dried, the weight, the shrinkage in weight, and the lateral shrinkage was carefully taken and tabulated. Then one pyramid of each specimen was burned without being previously heated. Many of those broke to pieces because of the violent action of the escaping gases caused by the rapid heating. The other pyramids were put close to the furnace and heated while the first were being burned. They were also heated to a red heat in the muffle

before being put in the furnace. The results in the second case showed a marked improvement.

In each case the pyrometric cones used were numbers 022, 03, 10, 30. The temperature at which they fuse is: 022 at 1,094 degrees, 03 at 1,994 degrees, 10 at 2,426 degrees, and 30 at 3,146 degrees, all being given as Fahrenheit.

In the second burning all these cones fused, showing a temperature of at least 3,140°F. or 1,730°C.

After they were burned, the weight, the shrinkage in weight, and the lateral shrinkage was again carefully taken and tabulated. Also the color and the condition was put down. From this data the following reports are made.

These tests were made under the writer's direction by Mr. Willis Richardson.

DATA TAKEN AFTER THE PYRAMIDS HAD AIR DRIED.

The first ten and also 58 and 59 are mahoganies.

Number	Weight	Shrinkage in Weight	Lateral Shrinkage
1	17, 18	11, 11	7/60, 7/60
2	24, 22	9, 9	6/60, 6/60
3	24, 24	10, 10	5/60, 5/60
4	24, 24	11, 11	4/60, 4/60
5	24, 23	10, 9½	7/60, 7/60
6	26, 23	11, 10	4/60, 4/60
7	28, 29½	12, 13½	7/60, 7/60
8	23, 24	12, 13½	4/60, 4/60
9	23, 23	13, 14	4/60, 4/60
10	28, 28	9, 9	4/60, 4/60
58	26, 26	14, 15	5/60, 5/60
59	25, 25	11, 12	4/60, 5/60
11	25, 24	9, 8	3/60, 4/60
12	26½, 26	8½, 8	5/60, 5/60
13	22, 25	7, 7	5/60, 5/60
14	31, 26	10, 8	5/60 5/60
15	26, 25	9, 9	6/60, 5/60
16	25, 26	6½, 7	3/60, 3/60
17	24, 25	7, 6	2/60, 2/60
18	27, 26	8, 8½	4/60, 4/60
19	27, 24	7, 6½	4/60, 3/60
20	28, 29	8, 8	3/60, 3/60
21	27, 27	7, 6	3/60, 2/60
22	28, 29	8, 8	6/60, 4/60
23	23, 23	8, 8	3/60, 3/60

DATA TAKEN AFTER THE PYRAMIDS HAD AIR DRIED Continued.

Number	Weight	Shrinkage in Weight	Lateral Shrinkage
24	32, 32	8, 8	3/60, 3/60
25	23½, 25	9½, 9	3/60, 3/60
26	32, 34	8, 8	4/60, 4/60
27	29, 30	7, 7	1/60, 2/60
28	30. 30	8, 7	4/60, 5/60
29	29, 31	6, 7	2/60, 2/60
30	27, 27	8, 8	5/60, 5/60
31	29, 32	8, 8	5/60, 5/60
32	29, 33	9, 9	5/60, 5/60
33	29, 29	7, 6	2/60, 2/60
34	25, 23	8, 9	6/60, 6/60
35	30, 28	8, 8	5/60, 5/60
36	29, 26	8, 8	2/60 2/60
37	28, 31	9, 10	5/60, 5/60
38	29, 28	7, 7	3/60, 3/60
39	30, 28	7, 7	3/60, 3/60
40	28, 30	14, 14	4/60, 4/60
41	28, 28	7, 7	3/60, 3/60
42	27, 27	6, 7	4/60, 4/60
43	33, 33	6, 6	2/60, 2/60
44	29, 28	7, 7	4/60, 4/60
45	35, 35	7, 7	2/60, 2/60
47	29. 30	6, 6	2/60, 2/60
49	28, 28	7, 6	4/60, 4/60
50	25 24	11, 11	1/60, 1/60
51	28, 28	8, 7	2/60, 2/60
52	25. 26	7, 8	2/60, 2/60
53	28, 29	6 7	4/60, 4/60
54	28, 28	7, 7	3/60, 3/60
55	24, 23	7, 6	3/60, 3/60
56	26, 27	7, 6	5/60, 4/60
57	28. 26	8, 9	4/60, 5/60

DATA TAKEN AFTER THE PYRAMIDS WERE FIRED.

No.	First Weight	Weight After Burning	Lateral Shrinkage After Burning	Remarks
1	26	15	3/16	Incipient fusion.
2	31	20	5/32	Dark brown, hard burned.
3	34	21	5/32	Dark red, hard burned.
4	35	20	2/16	Brownish red, hard burned.
5	32½	20	3/16	Dark red, hard burned.
6	37	22	3/16	Dark red, good, slightly cracked.
7	43	26	1/32	Red, slightly puffed, blubbered.
8	37½	24	1/6	Blue, incipient fusion, fair shape.
9	37	20	3/16	Dark red, very good, hard burned.
10	37	26	1/16	Brown, burned good, hard, firm.
58	41	21	3/16	Gray brown, slightly cracked, good.
59	37	21	3/16	Dark, incipient fusion, vitrified.
11	28	20	...	Dark gray, good shape.
12	34	24	5/60	Dark, incipient fusion, good shape
13	32	22	4/60	Brown, vitrified puffed, cracked.
14	34	25	1/16	Gray, vitrified, good shape.
15	34	Broken	in Furnace	Red half gone, good, hard.
16	31	22	3/16	Vitrified, good shape, gray.
17	31	22	7/60	Gray, vitrified, slightly cracked
18	34½	23	9/60	Red to dark, vitrified, cracked, good.
19	30½	32	4/60	Gray, vitrified, very good.
20	37	26	1/16	Gray, very good, red spot.
21	33	25	5/60	Brownish gray, cracked and puffed, slightly vitrified.
22	36	25	9/60	Pink, brown, gray, incipient fusion.
23	37	27	2/32	Brown, incipient, fusion.
24	40	30	1/16	Gray, vitrified, slightly cracked.
25	33	14	8/60	Brown, pink, vitrified, half broken away.
26	36	26	6/60	Very good, pinkish-gray color.
27	37	28	8/60	Pink, gray, vitrified, slightly cracked, good shape.
28	31	22	9/60	Blue, gray, incipient fusion at top.
29	37	29	4/60	Pink and gray, slightly cracked, good, body.
30	35	24	2/60	Brown, incipient fusion, cracked and puffed out of shape.
31	30	23	8/60	Shows iron vitrified.
32	38	25	....	Expanded, brown, incipient fusion, badly cracked, iron present.

DATA TAKEN AFTER THE PYRAMIDS WERE FIRED—Continued.

No.	First Weight	Weight After Burning	Lateral Shrinkage After Burning	Remarks
33	35	27	4/60	Pink, gray, slightly cracked, good body.
34	....	....	....	....
35	34	24	5/60	Very good, almost vitrified.
36	37	26	3/60	Brown, gray, vitrified, very good.
37	36	27	2/60	Brown, vitrified, slightly cracked.
38	36	25	....	Brown, vitrified, slightly cracked.
39	37	27	1/60	Cream colored, cracked, vitrified, slightly out of shape.
40	44	24	14/60	Gray, cracked slightly, good shape.
41	35	24	6/60	Pink to brown, out of shape, incipient fusion.
42	34	24	2/60	Slightly cracked, good shape.
43	39	30	1/32	Red, slightly cracked, incipient fusion.
44	36	26	1/16	Well burned, well vitrified, good body.
45	42	31	4/60	Pink, gray, cracked slightly, good body.
47	36	27	1/16	Red, vitrified, incipient fusion, good body.
49	34	24	5/60	Red, puffed, slightly cracked.
50	35	19	2/16	Orange color, slightly cracked good.
51	35	25	1/32	Cream colored, burned very good.
52	34	23	1/16	Gray, very good, vitrified, pink.
53	36	25	3/32	Red, very good body.
54	35	25	3/60	Gray, incipient fusion, fair shape.
55	29	20	1/16	Red, good shape, burned well.
56	33	24	7/60	Gray, vitrified, cracked, puffed.
57	36	20	6/60	Pink, cracked badly, broke and partly gone, vitrified.
1	⅓K37	24	8/60	Gray, burned very good vitrified.
11	⅓K	23	....	Gray, very good shape.
11	¼K41	26	2/16	Gray, very good body.

Remarks on Tests.

Shales showing a great deal of iron: Numbers 12, 18, 28, 54, 30, 32, 13, 25, 14.

1. Average lateral shrinkage: Between 4/60 and 5/60 of an inch.
2. Average shrinkage in weight: About 7 grams. Greatest shrinkage was 8 grams, least 6 grs.
3. Average condition of pyramids: Numbers 20 and 27 are in good condition, while numbers 30, 32, 13 and 25 are badly out of shape, puffed, cracked and broken.

Shales showing less iron: Numbers 21, 41, 27 and 20.

1. Average lateral shrinkage: Between 2/60 and 3/60 of an inch.
2. Average shrinkage in weight: Seven grams. Greatest shrinkage in weight was 8 grams.
3. Average condition of the pyramids: Numbers 20 and 27 are in good condition, while numbers 21 and 41 are badly out of shape, puffed and cracked.

The Mahoganies showing a great deal of iron: Numbers 1, 8 and 6.

1. Average lateral shrinkage: About 5/60 of an inch. Number 1 has a shrinkage of 7/60, while numbers 8 and 6 have only 4/60 of an inch.
2. Average shrinkage in weight: 11 grams before burning. 12 grams after burning.
3. Condition of the pyramids: All good and hard, very good shape.

The Mahoganies showing less iron are numbers 2, 3, 5 and 9.

1. Average lateral shrinkage: Between 5/60 and 6/60 of an inch. After burning 5/32 of an inch.
2. Average shrinkage in weight: Air dried, 10 grams. After burning, 12 grams.
3. Condition of the pyramids: All very good shape and hard.

General review of the Shales.

1. Average lateral shrinkage:
   - (a) Air dried, 4/60 of an inch.
   - (b) After burning, 6/60 of an inch.
   - (c) Makes 2/60 of an inch of shrinkage due to burning.
2. Average shrinkage in weight:
   - (a) Air dried, about 8 grams.
   - (b) After burning, about 10 grams.
   - (c) Makes a shrinkage of 2 grams due to burning.

General review of the Mahoganies.

1. Average lateral shrinkage:
   - (a) Air dried, 5/60 of an inch.
   - (b) After burning, about 5/60 of an inch.
   - (c) There is no difference in shrinkage due to burning.

2. Average shrinkage in weight:
   (a) Air dried, 11 grams.
   (b) After burning, 13 grams.
   (c) Makes an average shrinkage in weight of 2 grams due to burning.

Highest temperature reached in burning was at least 3,146 degrees Fahr. or 1,730 degrees C.

Only three of the pyramids were completely fused. Many of them were partially fused and several showed incipient fusion.

Extra good pyramids are numbers: 51, 44, 52, 47, 53, 55 and 14.

Kaolin and Shale Mixtures.—Mixtures of 1 to 3; 1 to 2 and 1 to 1 of some of the Chester shales and kaolins were made and the following data obtained after the pyramids were fired:

19A. Good shape, shows very slightly incipient fusion.
19B. Burned well, shows no fusion. Cream colored.
19C. Same as 19B except it is slightly cracked.
44B. Burned well, porous, buff colored.
44C. Good shape, vitrified, slightly cracked, hard.
47A. Soft and sandy, pink and gray color, very porous.
47B. Same as above, slightly cracked.
47C. Same as above, very porous, not vitrified.
51B. Burned very good, cream colored, no cracks, hard.
51C. Burned well, vitrified, very good.
52A. Burned well, cream colored, rather soft, not vitrified.
52B. Same as above.
52C. Same as above.
53C. Well burned, no cracks, pink colored, rather porous.

All the cones have held their shape well. Most of them could be fired at a higher temperature without fusing them. The kaolin mixture makes a much better fire resisting material than shales above.

DATA COLLECTED FROM FIRED SHALES AND MIXTURES.

Number.	Vol. C. C.	Difference in Wet and Dry Grams.	Per Cent of Porosity.	Number.	Vol. C. C.	Difference in Wet and Dry Grams.	Per Cent of Porosity.	Number.	Vol. C. C.	Difference in Wet and Dry Grams.	Per Cent of Porosity.
1	8	1	12.5	24	19	0	0	51	11	1	9.0
2	9	1	11.1	25	22	3	13.6	52	12	0	0
3	9	1	11.1	26	13	3	23	53	11	1	9.0
4	10	4	40	27	14	2	14.2	54	13	2	15.3
5	9	1	11.1	28	15	2	13.3	55	10	1	10
6	9	1	11.1	29	13	1	7.7	56	14	0	0
7	22	0	0	30	20	1	5	..	..	..	..
8	14	1½	10.7	31	10	1	10	1⅓K	12	1½	12.5
9	9	2	22.2	32	26	1	3.9	11¼K	13	1	7.7
10	12	2	16.6	33	12	2	16.6	..	..	..	..
58	10	3	30	34	..	0	0	19A	14	2	14.2
59	9	1	11.1	35	13	0	0	19B	14	3	21.4
11	14	1	7.1	36	15	0	0	19C	13	4½	34.6
12	19	0	0	37	30	0	0	44B	12	5	41.6
13	22	0	0	38	19	1	5.2	44C	11	1	9.0
14	14	0	0	39	22	1	4.5	47A	10	3	30
15	..	..	..	40	12	1	8.3	47B	12	4	33.3
16	14	2	14.2	41	16	1	6.2	47C	12	5	50
17	14	1	7.1	42	15	1	6.6	51B	12	3	25
18	12	1	8.3	43	20	0	0	51C	10	1	10
19	10	0	0	44	14	1	7.1	52A	13	4	30.7
20	12	1	8.3	45	26	1	3.8	52B	11	4	36.3
21	14	0	0	47	10	0	0	52C	12	5	41.6
22	18	3	16.6	49	14	1	7.1	53C	12	4	33.3
23	10	1	10	50	9	3	33.3				

Malinite.

A refractory substance called "Malinite" is manufactured out of a mixture of Lawrence County kaolin, from the Dr. Gardner place, and fire clay. Three samples were tested by R. W. Hunt & Co., of Chicago, as follows:

"Three samples of Malinite refractories were selected, one white, one mottled and one brown. Portions of these brick were cut out and shaped into cones and mounted into a pat of Malinite, together with pyrometric cones numbered 30, 32, 34, 35, 36, 37, 38 and 39. After drying, the pat holding the pyrometric cones and test pieces was placed in an electric

furnace of Hoskins manufacture, the current turned on and heating continued until the melting of Cone No. 39.

The tests were started about 2:30 p. m., August 21st, and completed at 7:55 p. m. the same date. The atmosphere of the surface was reducing. The tests were conducted in the presence of J. H. Campbell, A. Malinovszky and W. W. Ittner. On August 22nd, the pat was taken from the furnace and the specimen of brick examined. There was no indication of fusion on the three samples tested. The temperature reached

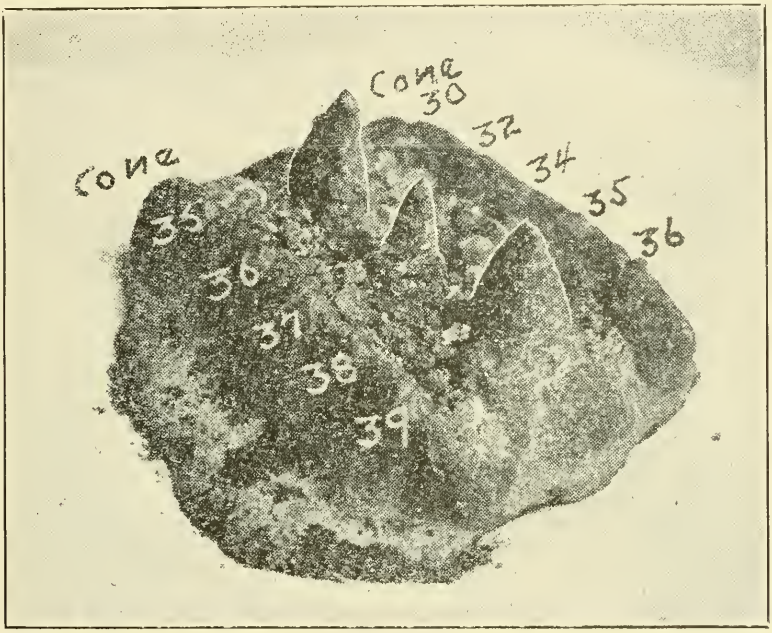

Plate XLVII. Showing three cones of Malinite after being tested at a high temperature. The numbers mark the positions of the pyrometric cones which were all fused.

was 3,542 degrees F. or better. A photograph of the test pat is attached herewith.

Referring to this photograph, the three samples of Malinite refractories will be noted in the center; on each side the numbers show the location of the pyrometric cones. Between cones Nos. 30 and 36 is the white specimen. Between Nos. 34 and 37 is the mottled specimen. Between Nos. 36 and 39 the brown specimen. Examining these specimens with a glass, the complete absence of fusion is apparent.

Load Tests Under Heat.

Full specimens of brick were placed in a furnace and heated up to 1,350 degrees C., about 2,500 F., in a period of 4½ hours, and held at that temperature for 1½ hours. Specimens were allowed to cool in the furnace over night. As tested the brick was set on end and a load of 25 pounds per square inch applied during the heating and cooling, as provided by specification of the American Society of Testing Materials C 16-17 T.

Description of Sample	Mottled	Brown
Dimensions under compression	2.50 in. x 4.56 in.	2.55 in. x 4.50 in.
Height as tested	9.35 in.	9.43 in.
Area under compression	11.40 sq. in.	11.47 sq. in.
Total load applied	285 lbs.	287 lbs.
Load per square inch	25 lbs.	25 lbs.
Height after test	9.34 in.	9.43 in.
Per cent contraction	11/100	None

Neither sample showed signs of checking after the above test.

COLD CRUSHING TEST.

Description of Sample	Mottled		Brown	
Test Number	1	2	3	4
Specimen tested	On end	Flat	On end	Flat
Dimensions under compression	2.56″x4.66″	9.37″x4.54″	2.45″x4.59″	9.39″x4.54″
Area under compression	11.93 sq. in.	42.54 sq. in.	11.25 sq. in.	42.63 sq. in.
Height as tested	9.42 in.	2.49 in.	9.31 in.	2.50 in.
Maximum load	16,750 lbs.	92,290 lbs.	12 430 lbs.	73,680 lbs.
Crushing strength (lbs. per sq. in.)	1,404 lbs.	2,170 lbs.	1,105 lbs.	1,705 lbs.
Failure	Regular	Regular	Regular	Regular

Slagging Test.

Specimens were heated to 1,350 degrees Centigrade, 2,500 degrees F., in a period of five hours. 12.6 grammes of basic Open Hearth slag were then placed in the cavity previously prepared in the samples and held at the above temperature for

two hours and allowed to cool in the furnace. Size of cavity, 1⅝ in. diameter by 9/16 in. depth.

Description of sample	Mottled	Brown
Slag used	Basic Open Hearth	
Slag penetration sq. in.	0.57	0.48

A test was made on each sample, using Powdered Silica brick and Powdered Magnesia brick. These materials showed no penetration under the above test.

The above slagging test is practically in compliance with the specification of the American Society of Testing Materials C. 17-17 T., except the weight of slag and diameter of cavity. This was changed in order to permit the placing of three specimens in the furnace under the same conditions at the same time.

Chemical Analysis.

Chemical analysis of portions of the three specimens subjected to fusion tests follows:

	White	Mottled	Brown
% Silica	44.90	46.62	47.50
% Iron Oxide	.71	.71	4.60
% Aluminum Oxide	52.39	50.91	46.36
% Calcium Oxide	1.12	1.16	.60
% Magnesium Oxide	.28	None	None
% Sodium Oxide	.04	.24	.26
% Potassium Oxide	None	Trace	.09
% Titanium Oxide	.10	.28	.60

Transverse Test.

A transverse test was made on two samples of each, mottled and brown. The average of these two tests are:

Test.	No. 1.	No. 2.
Description of sample	Mottled	Brown
Average dimensions	4.615 x 2.50 x 9.365	4.425 x 2.465 x 9.36
Distance between supports, C to C	8 in.	8 in.
Breadth as tested	4.615	4.425
Depth as tested	2.50	2.465
Maximum load sustained	1,140	1,390
Modulus of rupture	476	621

Specific Gravity.

The determination of the specific gravity was made upon two specimens each of mottled and brown, the results of which are:

	Mottled.	Brown.
Test No.	1.	2.
Weight used	60 grams	60 grams
Volume	21.1cc	21.2cc
Actual specific gravity	2.84	2.83

Conclusion.

The above tests indicate a refractory with a very high fusion point and one that under temperature maintains its shape when subjected to pressure. It resists slagging action well, and the uniform penetration of the slag indicates a good mixture of the materials before molding. The absence of slagging with the Magnesite brick and Silica brick suggest that Malinite refractories may be placed in contact with the other refractory materials without slagging action, and that the refractory possesses neutral properties."

Encaustic Tile.—The stained kaolins which have been reduced to a moderate degree of plasticity by weathering, the introduction of colloidal iron oxide and possibly to some extent by bacterial action have been used in the manufacture of encaustic tile. It is possible to use the non-plastic kaolin for this purpose by mixing with it some plastic clay to furnish the proper bonding power, though it does not seem desirable to use the better grades of kaolin for this purpose, since the stained kaolin is more abundant and its use more restricted.

Paint Pigment.—The pure white kaolin may be used in the manufacture of white paint since it is not readily soluble in acids and would be little affected by atmospheric agents of decomposition. To be used for this purpose the kaolin should be ground very fine in a ball mill and the coarser particles separated by means of the blower process.

Kaolin is also used in the manufacture of ultramarine, which was formerly obtained by the grinding of lapis lazuli. The artificial pigment is manufactured from kaolin, charcoal, silica, soda and sulphur, by fusion and roasting, after which it is powdered. It is used in paints and dyes.

ULTRAMARINE BLUE MIXTURES.

Ultramarine.	Pale.	Medium.	Dark.
Kaolin or clay	100	100	100
Soda	9	100	103
Glauber salt	120	0	0
Carbon	25	12	16
Sulphur	16	60	117

The raw materials which are used in the manufacture of Ultramarine are enumerated in the above table. The clay used may be china clay, pottery clay or kaolin of good quality. The clay should be free from excessive amounts of iron or manganese and should be finely divided. The soda used should be a good quality of carbonated soda ash. The glauber salt should be free from acid and iron compounds, and should be

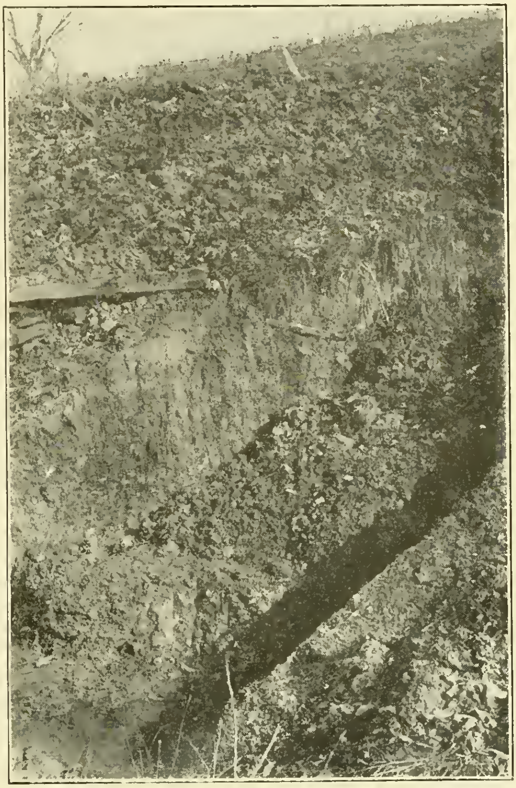

Plate XLVIII. Outcrop of mahogany clay in Monroe County.

reduced to a fine powder. The sulphur should be a good quality of stick sulphur reduced to a finely divided state. The carbon should be a good grade of pine trunk charcoal, containing not more than four per cent. water and ground in a ball mill to a fine powder. Coal may be used if it is high in carbon and free from sulphur and iron. The silica may be finely ground quartz or Rieselguhr. The tripoli of southern Illinois would probably be admirably adapted to this purpose.

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Charcoal produced from rice husks contains both carbon and silica and may be used in place of carbon and silica.

Manufacture.—Ultramarines rich in silica are made by the direct method. The processes involved are: Mixing, roasting, lixivating, wet-grinding, levigating, pressing, drying and sifting. The roasting is done in mass ovens or in shaft furnaces.

Plate XLIX. Outcrop of kaolin in Monroe County.

In the indirect method some ultramarines poorer in silica are manufactured. The preparatory stages are the same as in the direct method. The furnaces used are muffle or crucible or shaft or cylindrical retort furnaces.

Paper Manufacture.—Talc, chalk and other substances are used as a filler in the manufacture of paper, and some of

minerals so used require expensive methods of preparation. The better grade of Indiana kaolin could be used for this purpose and compete, so far as cost is concerned, with other materials.

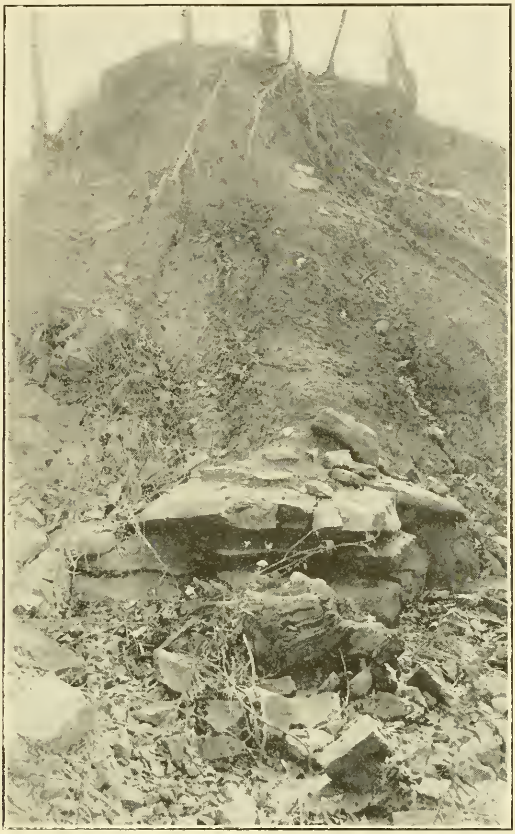

Plate L. Chester limestone surrounded by mahogany maroon and olive green shale. Monroe County.

Other Uses.—It is possible to use Indiana kaolin in the manufacture of filters, as a filler for varnishes, for fulling cloth, as a catalyzer in the manufacture of poison gas and as an abrasive in buffing.

Chapter VI.

The Geographical Distribution of Kaolin in Indiana by Counties.

General Distribution.—The kaolin of Indiana occurs along the outcrop of the shales and sandstones of the Chester division of the Mississippian rocks and also along the contact of the Mississippian with the Pennsylvanian rocks. This line of contact extends from Benton County, north of the Wabash River, on the northwest, to Perry County, on the Ohio River, at the south. The line passes through the following counties: Benton, Warren, Fountain, Parke, Montgomery, Putnam, Clay, Owen, Monroe, Greene, Lawrence, Martin, Orange, Dubois, Crawford and Perry. (See maps accompanying this report.) Outcrops of the contact are concealed under a glacial overburden in the northern portion of the area. From Monroe County southward the line of contact lies through the non-glaciated portion of Indiana. In this region outcrops along the line of contact are more abundant. The width of the accessible area of contact is variable, but is about twelve miles in width in the northern portion and about eighteen miles in width in the southern portion. The attenuated margin of the Pennsylvanian has been eroded in this region to such an extent that as a rule its rocks are found only on the tops of the high ridges which form the divides between the present drainage lines. In places these ridges rise 300 or more feet above the adjacent valleys and the line of contact between the Mississippian and Pennsylvanian occurs often 200 or more feet above the valleys. The ridges are decidedly irregular and their margins serrated by the indentation of minor drainage lines with their intervening spurs. The ridges are usually capped with a soft sandstone which crumbles easily, works down over and conceals the outcrops of the kaolin along the contact zone. The mantle of sand is so general along the contact that good outcrops occur only under exceptional conditions. Sometimes a stream cuts in against the line of contact and exposes the kaolin. In other places a spring may discharge its waters from beneath the bed of kaolin and the quantity of water may be sufficient to carry away the detritus and form a perpendicular face at the outcrop.

Kaolin has not been reported from all the counties along the contact zone. It has been found in Owen, Greene, Monroe, Lawrence, Martin and Orange. The only county in which there has been a serious attempt toward development is Law-

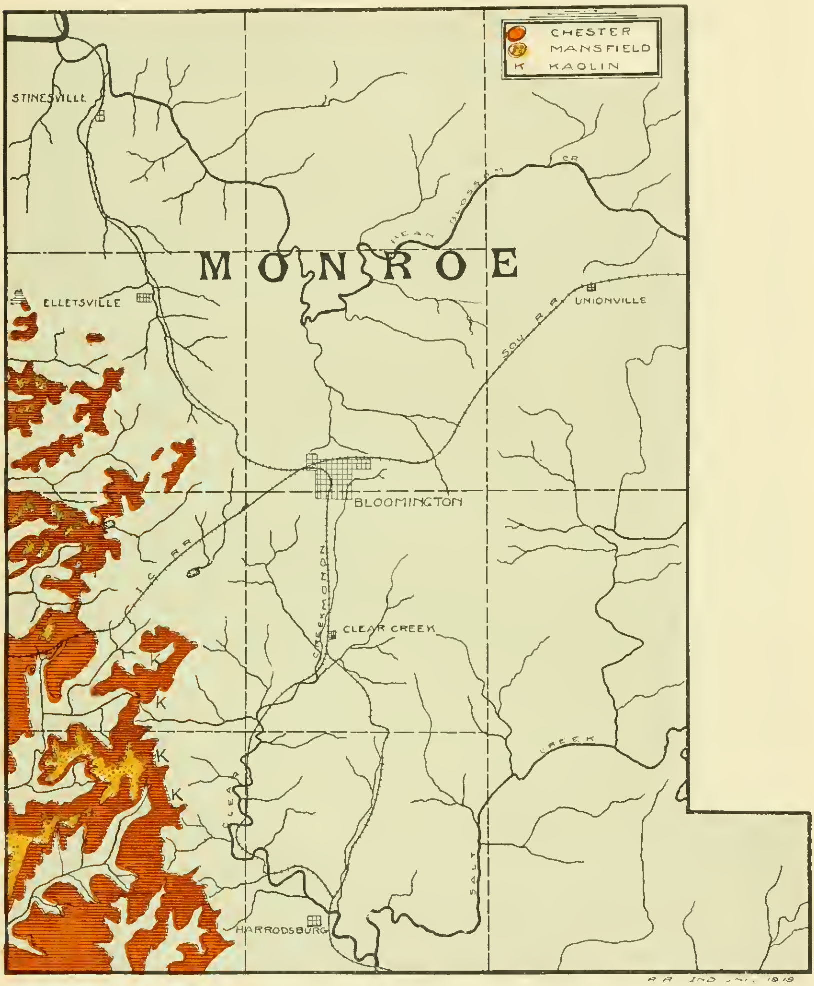

Plate XXVIII.

rence County. Even here actual production has been confined almost entirely to one-half section and to only a small portion of that. Outcrops of white clay have been found in many places and test drifts, pits and drill-holes have revealed the presence of a white clay in many sections in the southwestern

Plate XXIX. Entrance to the Orchard-Timberlake mine in Monroe County. White kaolin on the dump in front of entrance.

part of the county. Explorations have been more extensive in this county than in any other county in the Indianaite belt. For this reason, prospects appear best in this county. Martin County probably offers the next best field for exploration and development and Orange, Greene, Monroe and Owen would perhaps follow in that order.

Monroe County.

General Statement.—This county lies largely in the unglaciated portion of Indiana and the bed-rock formations are well exposed. The Monon railroad crosses the county from north to south near the center of the county and the Illinois Central crosses it from east to west through Bloomington and sends a branch from that point south to Victor parallel with the Monon. The kaolin outcrops occur in the southwestern part of the county within from one to three miles of these roads. If enough white kaolin should be found to warant development on a large scale the transportation situation would present no serious difficulties.

At the present time there are no ceramic industries in this county and no established facilities for making use of the kaolin locally for ceramic purposes.

The greater number of outcrops of kaolin occur below the Elwren sandstone of the Mississippian and only a few at the base of the Mansfield sandstone of the Pennsylvanian.

During field work in 1917 the writer's attention was attracted to an outcrop of reddish colored clay containing fragments of a white clay near the public road in Section 3 of Indian Creek township. A later examination of the white clay showed it to be kaolin, Indianaite, a variety of halloysite.

In the spring of 1918 Mr. Dick Hall of Bloomington located a number of outcrops of the same kind of clay in the township. One of these outcrops is on the public road near the John Koontz place in Section 10. The section exposed consists at the bottom of a shale containing sandy layers near the upper part, overlying this is a layer of mahogany colored clay of a thickness of thirty inches, containing fragments of kaolin, and above is a five-foot layer of sandstone. The kaolin occurs under and in most cases immediately in contact with the sandstone. Where the sandstone is compact and unfissured the Indianaite is more abundant. The thickness of the mahog-

any clay is variable, pinching and swelling. In some places it may have a thickness of four feet and pinch down to less than half that amount in less than ten feet.

Plate XXX. Mass of white kaolin from the Orchard-Timberlake mine in Monroe County. Kaolin lies below the Elwren sandstone.

At one point in Section 28 of Van Buren township, in a sandstone ledge, there is a thin layer made up of the fragments of kaolin. This occurrence shows that the Indianaite

had been formed, eroded and redeposited. Below the sandstone there occurs a layer of mahogany clay which contains small fragments of Indianaite. The mahogany clay rests on a thin bed of sandstone which in turn rests on a bed of greenish colored shales. In the shale there are irregular lens-like masses of limestone. Where exposed at the surface these limestone masses are surrounded with the mahogany clay in which fragments of the white kaolin were found.

Distribution.—In Van Buren township kaolin has been found in Sections 27, 28, 33 and 34. The outcrops occur on the slopes of a ridge which rises about 900 feet above sea level and forms a part of the divide between Clear Creek on the east and Indian Creek on the southwest. On the road which connects West pike with the Rockport pike, passing through the center of Section 28, and intersecting the above mentioned ridge, there are a number of outcrops of kaolin. On the northern slope of the ridge at the point where the road crosses it, there is an outcrop of mahogany clay which contains a considerable quantity of kaolin. Underlying the clay and separating it from a bed of shale is a thin layer of sandstone. A bed of sandstone having a thickness of twenty-five feet overlies the clay. The clay has a thickness of four feet at the outcrop but pinches down to about half that in a distance of six feet. The kaolin occurs in hard irregular fragments and also as white plastic streaks in the red colored clay. On the same slope below this outcrop there are some greenish gray shales containing irregular masses of limestone surrounded by mahogany clay. This clay also contains some fragments of the white kaolin.

On the same ridge farther east on the north side there is an outcrop of kaolin six feet thick on the side of a sink hole. On the south side of this ridge in the southeast quarter of Section 28, kaolin occurs under the sandstone, capping the top of the ridge, at about the same elevation as that on the north side. West of the road above mentioned, in Section 33, there is an outcrop of mahogany clay containing considerable Indianaite. The clay occurs between layers of sandstone of very fine grain. The overlying sandstone has a thickness of about thirty feet. The mahogany layer is irregular in thickness, pinching and swelling. Similar outcrops have been found in Section 27 on the southwest side of the ridge and in Section 34 on the east side.

Indian Creek Township.—Indications of the presence of kaolin have been found at several places along the ridge which forms the divide between Indian Creek and Clear Creek in

Plate XXXI. Outcrop of mahogany clay and white kaolin under Elwren sandstone in Monroe County. See note book and above.

this township. In Section 3, outcrops occur in the west half of the section. In Section 10, outcrops of mahogany clay occur at several points, also in Sections 9 and 17. In the northwest

corner of Section 10, near the public road, there is an outcrop of a layer of mahogany clay having a thickness of about 30 inches in places but thinning down to about half that in other places. White kaolin occurs in the clay in small irregular fragments which are most abundant under the compact and unfractured portions of the roof of sandstone. The underlying rock is a shale which passes into very sandy shale and lenses of sandstone just below the mahogany clay. The geological section exposed at this point is as follows:

No. 8 (top) Shale	5 feet.
No. 7 Sandstone in thin beds	5 feet.
No. 6 Shale, sandy	6 feet.
No. 5 Sandstone	5 feet.
No. 4 Shale	20 feet.
No. 3 Sandstone, thick layers	10 feet.
No. 2 Mahogany clay and Indianaite	2½ feet.
No. 1 (bottom) Shale, sandy toward the top	12 feet.

This mahogany clay lies near a slight unconformity in the Mississippian system of rocks. The shales above and below the mahogany belong to the Mississippian. The sandstone above is the Elwren sandstone of the Chester group.

State of Development.—Small pits have been dug at several places on the outcrop of the mahogany clay but no serious attempt at development has been made. In order to determine whether the kaolin occurs in sufficient quantities to warrant commercial development will require the drilling of wells along the sandstone ridge at some distance from the outcrop. Near the outcrop the clay is nearly always stained with oxides of iron. The number and thickness of the outcrops offer promise of workable beds of the white clay. A tunnel has been driven at one point to a distance of 130 feet. Six feet of fairly white kaolin was found in this tunnel, and the indications are that a marketable quantity exists.

The presence of kaolin in Monroe County was mentioned by G. K. Greene[1] as follows: "Traces of kaolin, mere waterworn fragments, are occasionally found upon the surface. No beds of this deposit are found in Monroe County."

[1] 2nd Annual Report Indiana Geological Survey, p. 447.

Lawrence County.

General Statement.—The kaolin-bearing formations of Lawrence County are confined to the western portion. The greater part of the subsurface is occupied by formations of Mississippian or Lower Carboniferous age. The oldest of these formations forms the bedrock in the eastern part of

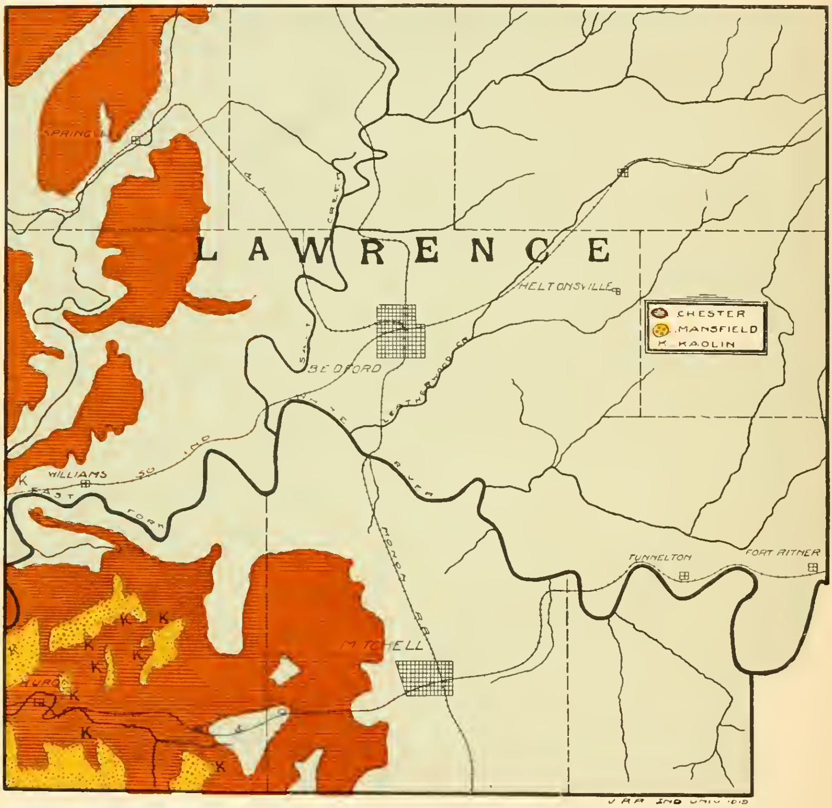

Plate XXXII. Lawrence County.

the county, and is bordered on the west by the outcrop of the Harrodsburg limestone. The central part of the county is occupied by the Salem (Bedford) and Mitchell limestones. The Chester (Huron) limestones, sandstones and shales, capped on the higher ridges with the Mansfield (Pottsville) sandstone of the Pennsylvanian or Upper Carboniferous occupy the western portion. In this portion of the county the topography is more rugged and problems of transportation

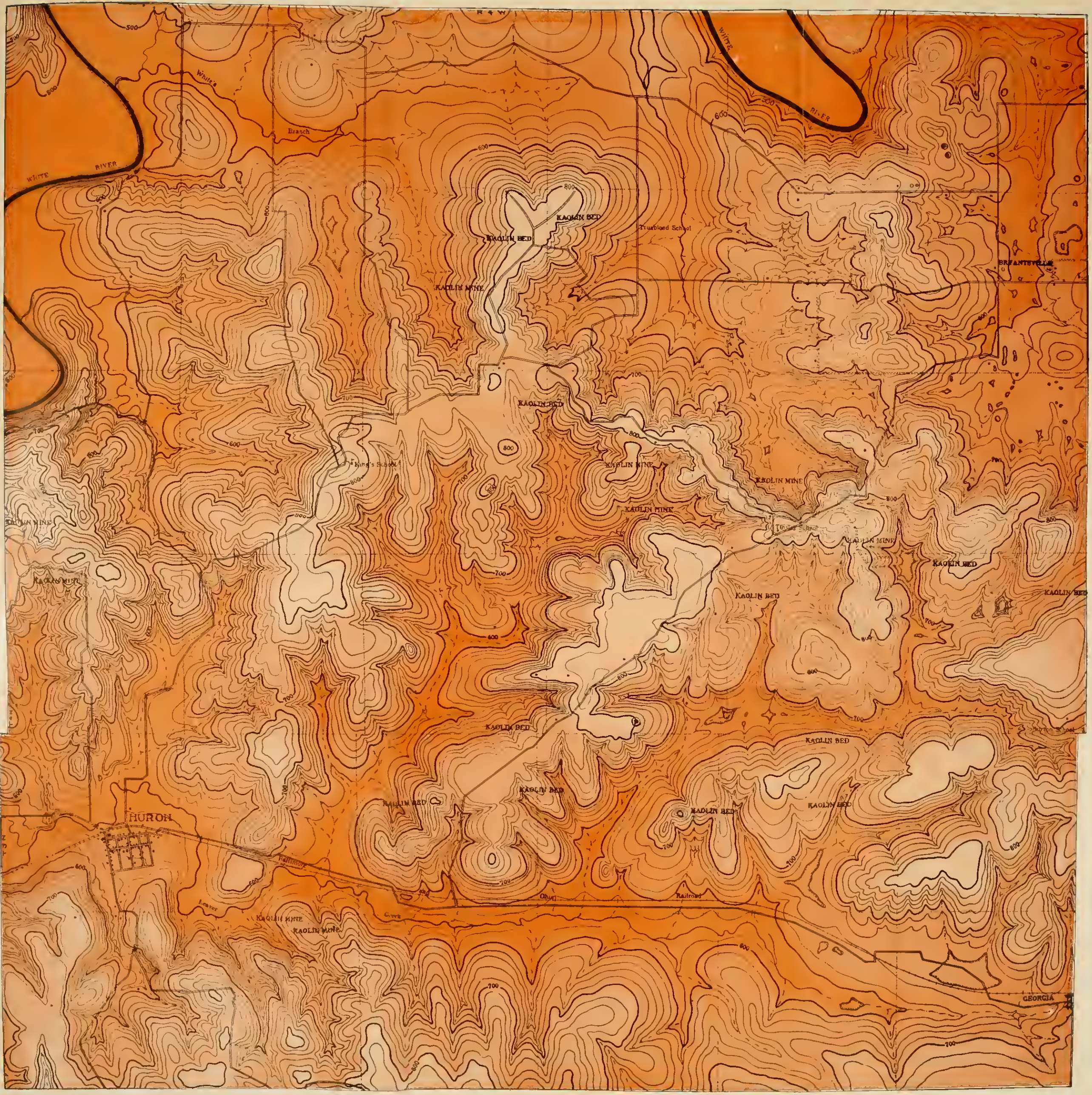

Plate LII. Topographic map of a part of Lawrence County.

more difficult and it is in this region that the kaolin deposits occur.

The Monon railroad crosses the county from north to south near the central portion and a branch of it traverses the northwestern portion of the county, connecting with the main line at Bedford. The B. & O. S. W. railroad crosses the southern part of the county from east to west, intersecting the Monon at Mitchell. Kaolin deposits occur on both sides of this railroad and near it in the southwestern part of the county. The Southern Indiana railroad crosses the county from east to west near the central part and intersects the Monon at Bedford. This road passes near kaolin deposits in the western part of the county. The greater part of the kaolin which has been shipped thus far has been from Huron on the B. & O. S. W. railroad, but smaller shipments have been made from Williams on the Southern Indiana railroad. No industries for the utilization of the kaolin have been established in Lawrence County and all kaolin mined has been shipped long distances.

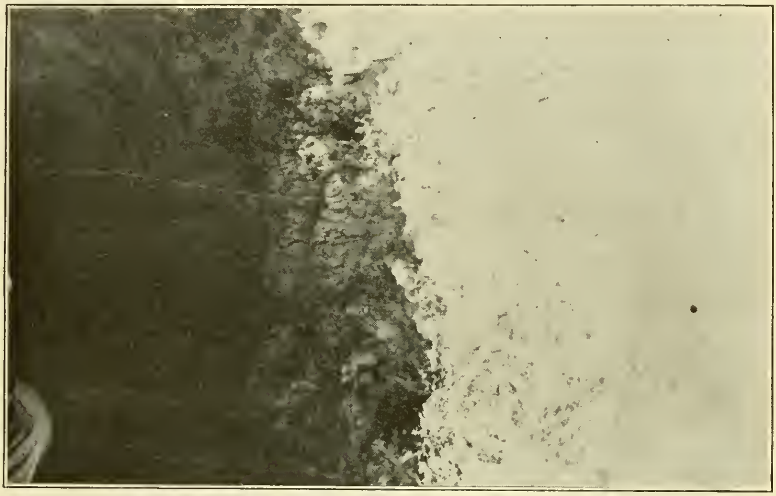

Plate XLIV. Six feet of white kaolin in an entry in the Gardner mine.

Spice Valley Township.—In the east half of Section 21 there is a high ridge of sandstone and shales which has upon its slopes a number of exposures of kaolin. These exposures occur near the contact between the Mansfield and the Chester formation, and to a limited extent at least, within the Mans-

field. The thickness of the kaolin varies from five to eleven feet, the average thickness being not far from six feet. In appearance the kaolin, in its upper portion is white and com-

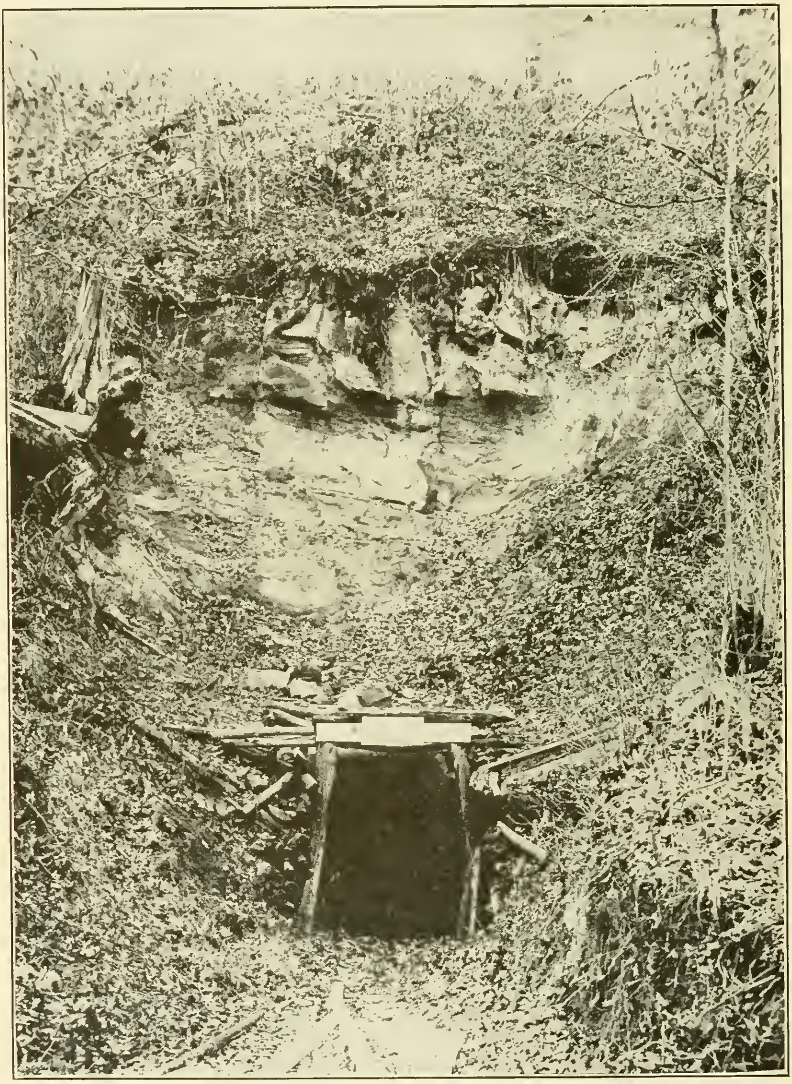

Plate XXXIII. Entrance to Gardner mine, Lawrence County. Mansfield sandstone above containing a thin layer of kaolin.

paratively free from discoloration. In the lower portion it contains sandstone masses and is often discolored with oxide of iron. Two mines have been opened in this section; the

west mine is a drift which is driven on the deposit to a depth of about 200 feet. The room and pillar system of mining was used and the pillars left were forty to fifty feet in diameter. This entry was driven from the west towards the east. The north mine entry is located about three-quarters of a mile north of the west entry and was driven south about 300 feet. Side entries were driven at intervals of about twenty-five feet. The room and pillar system was used in this mine and a large quantity of kaolin has been removed from it. (See Plate XLI.) The kaolin rests on the Elwren shale at an elevation of about 700 feet above sea level.

In Section 28 an outcrop of kaolin occurs in the northern part of the northeast quarter and also in the southeast quarter. An outcrop of mahogany clay occurs in the public road in the northwest quarter. In Section 22 indications of kaolin are found in the west half. Mahogany clay and disseminated white fragments occur at one point. There has been no development in this section. In Section 29 there are indications of the presence of kaolin in the east half. There has been no development except a small entry which encountered the mahogany but did not pass through the weathered zone. In Section 30, R. 2 W., drillings were made in the southwest quarter and kaolin was reported from these drillings. Kaolin occurs under the Cypress and under the Mansfield on the Hardinsburg shale at about 690 feet above sea level. In Section 31 the northwest quarter of this section is reported to contain kaolin, the data having been obtained from drill holes. In Section 4, kaolin has been found by explorations made by the American Aluminium Company in both the northeast and northwest quarters. The kaolin lies below the Mansfield and rests on the Elwren shale. Four or five feet of kaolin is revealed in one of the openings. In Section 34 indications of kaolin have been found in the northwest, northeast and southwest quarters. In Section 35 an outcrop of mahogany occurs in the northwest quarter. This outcrop has been explored by a short entry. The other three quarters contain indications of kaolin. In Section 36 kaolin indications have been explored in the northwest and northeast quarters. White kaolin was found in the entries. In Section 8 there is a deposit of kaolin in the northeast quarter which has been explored by drill holes and by entries. The kaolin rests on Elwren shale and under-

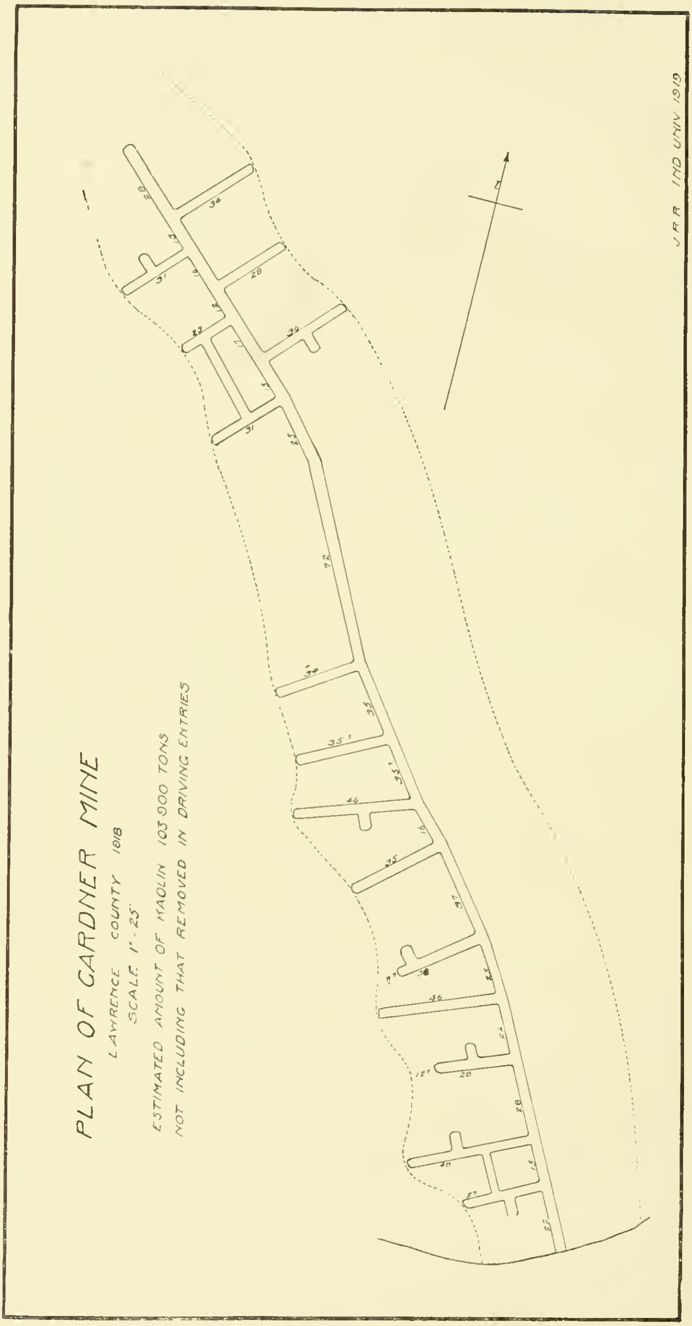
PLAN OF GARDNER MINE
LAWRENCE COUNTY 1918
SCALE 1"-25'
ESTIMATED AMOUNT OF KAOLIN 103 900 TONS
NOT INCLUDING THAT REMOVED IN DRIVING ENTRIES
JRR IND UNIV 1919

Plate LI.

lies Mansfield. Two entries have been driven. In Section 18 indications occur in all four quarters. Some outcrops have been explored by short entries. In Section 13 indications have been found in the northwest quarter. A small entry has been driven in the outcrop and some white clay obtained. In Section 2 indications of kaolin have been found in the northeast quarter and explorations have been made by entry and drilling. The southeast quarter also shows indications. In Section 3 the east half shows indications of the presence of kaolin and small explorations has been made in one place. In the N. E. quarter of the N. E. quarter of Section 30, T. 4 N., R. 2 W., a deposit of mahogany clay and white kaolin occurs at the contact between the Elwren shale and the Mansfield sandstone which has a thickness of 50 or 60 feet. Below the contact the Reelsville limestone occurs at 785 and the Beaver Bend limestone at 760 feet. They are separated by about 25 feet of Brandy Run shale. Two openings have been made at the kaolin horizon, one in a shaft 18 feet deep, the other a tunnel. Some white kaolin was found in each but neither extended into the deposit far enough to secure a good sandstone roof and consequently the kaolin is much stained. The ridge of Mansfield at this point extends in a curve toward the northeast for more than one-half mile.

In Section 26, near the S. E. corner, mahogany clay containing some white kaolin occurs at the contact between the Mansfield and the Sample shale, evidently at the top of the Sample, since a few bowlders of Beaver Bend limestones were found in the mahogany near the entrance of a tunnel being driven into the kaolin deposit by Dr. John Laughlin of Bedford. The Mansfield at this point has a thickness of 180 feet and has been deposited in a depression in the eroded surface of the Chester. Beneath the mahogany which has a thickness of from 4 to 6 feet there is about 20 or 25 feet of shale resting on the top of the Mitchell limestone.

In Section 25, about one-fourth of a mile east of the above outcrop, the Mansfield contact, at approximately the same elevation, exhibits a layer of stained kaolin.

About one-fourth mile north and a little east of the center of Section 36 the basal member of the Mansfield consists largely of uncemented sands which have been eroded into a badland type of topography. The Mansfield rests on a bed

of kaolin, a part of which is unstained. The full thickness of the kaolin stratum is not revealed but it is several feet thick and rests upon a bed of maroon shale which changes into olive-green below. The elevation of the kaolin at this

Plate XXXIV. Entrance to Phipps mine east of Huron. Kaolin resting on Elwren shale and containing a few Beech Creek limestone boulders. Mansfield above, contact rising toward the south.

point is five feet higher than it is in the S. E. corner of Section 26.

Across the ridge in Section 35, southwest of the kaolin outcrop in Section 26, the contact of the Mansfield and Chester

is about seventy feet higher than at the latter place. The Mansfield at this point rests on kaolin which has been formed from the Elwren shales. The unconformity has a steep dip, falling seventy feet in about one-half mile.

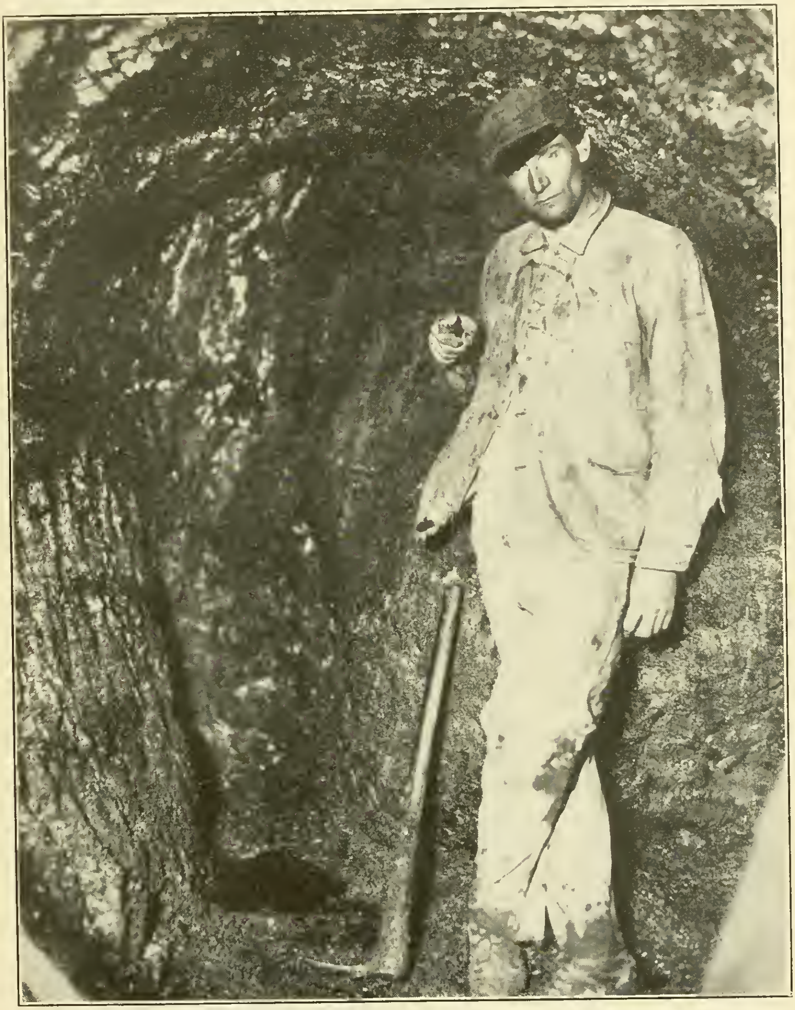

Plate XXXV. White kaolin in mahogany clay in Phipps mine, east of Huron. Limestone boulder at right. Beech Creek on Elwren shale.

In the N. E. quarter of Section 27 a kaolin outcrop occurs at the Mansfield contact with the Chester at about 720 feet. The outcrop exhibits four or more feet of mahogany and white kaolin. The thickness of the Mansfield is 120 feet at this

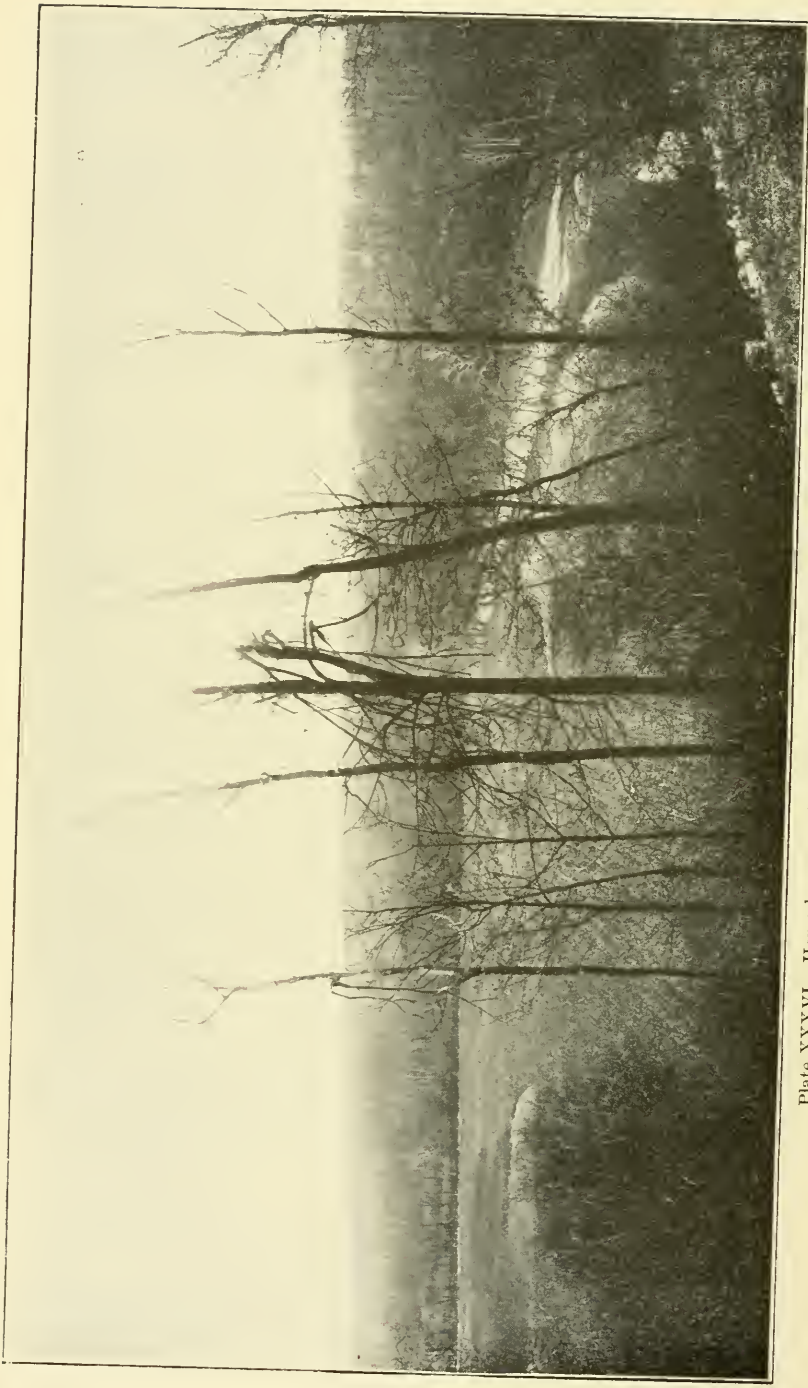

Plate XXXVI. Horseshoe curve in White River in the area mapped in Lawrence County.

point and the prospects for unstained kaolin under the ridge are good. In the southwest quarter of Section 27 a ridge capped with Mansfield sandstone occupies the north part of the quarter. Beneath the Mansfield there is a stratum of stained kaolin which rests on the Elwren shale. The kaolin contains a few much weathered limestone bowlders which belong to the Beech Creek limestone. In Section 5, near the northeast corner, mahogany clay lies underneath the Cypress sandstone. In Section 6, in the northwest quarter, kaolin occurs beneath the Mansfield at an elevation of about 90 feet above the Station at Huron; also below Cypress sandstone.

Indian Creek Township.—In Section 6 there is an outcrop of kaolin underlying the Mansfield sandstone in a gravel pit north of the Southern railway. The kaolin rests on the sample shale at an elevation of 587 feet above sea level.

Marion Township.—In the northwest quarter of Section 17 indications of kaolin have been found. In the southeast quarter of this section an outcrop of mahogany clay occurs. This outcrop has been explored by a drift entry and shaft and considerable white material has been found.

ORANGE COUNTY.

General Statement.—The geological conditions in the western portion of Orange County are favorable to the occurrence of kaolin. The higher lands are occupied by the Mansfield sandstone while the stream valleys and lowlands contain the outcrops of the Chester formations. The outcrops of kaolin so far encountered have been in the northwest portion of the county and the railroad facilities for this portion are not good. The Monon lies too far east and the B. & O. S. W. runs not quite as far away on the north. The topography is rugged so that transportation over the public roads would be more expensive.

Orangeville Township.—In the northeast quarter of Section 10, near the north line of the county, there are several outcrops of kaolin. The geological section exposed in the public road at this point is as follows:

No. 6	(Top) Sandstone (Cypress)	35 feet.
No. 5	Mahogany clay with white particles	10 feet.
No. 4	Greenish clay and thin bedded sandstone and limestone	88 feet.

No. 3	Limestone (Beaver Bend)	23 feet.
No. 2	Shale, thin bed of coal and sandstone (Sample)	21 feet.
No. 1	Limestone (Mitchell)	18 feet.

All quarters of this section contain outcrops of kaolin, some of which exhibit considerable white material. Indica-

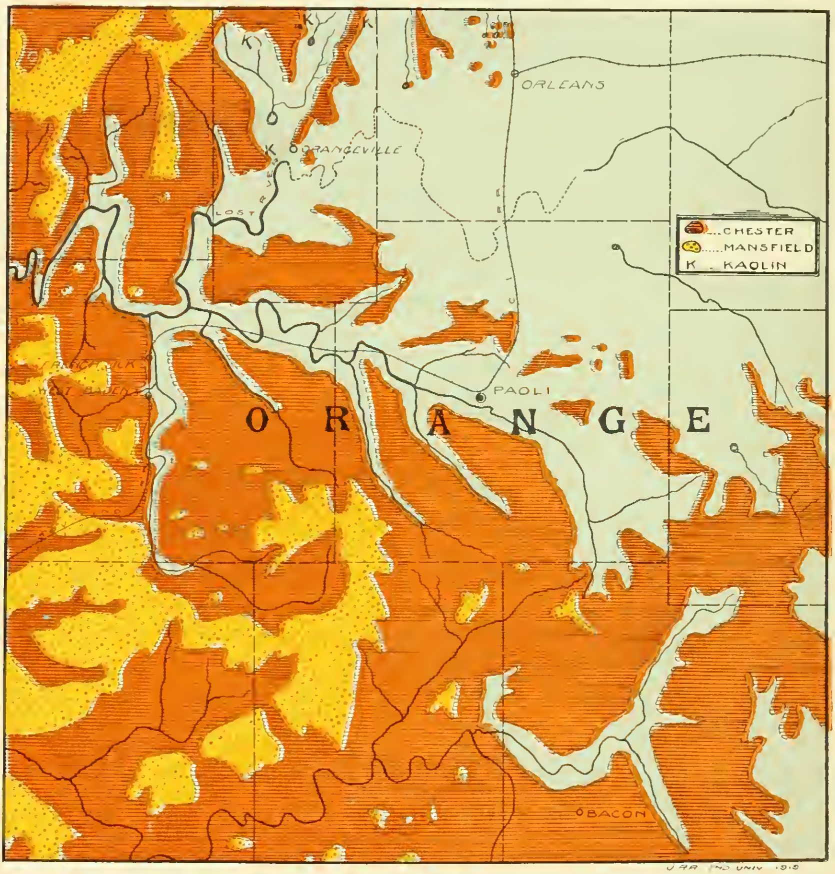

Plate XXXVII. Map of Orange County.

tions of kaolin have also been found in Section 20. In Section 32, white kaolin occurs in a cave. It lies above the Mitchell limestone and below the Sample sandstone. In Section 2 there is an outcrop of mahogany clay in the public road in the northwest quarter. The mahogany clay rests upon a clay which in

turn rests upon limestone. The overburden is sandstone. In Section 20,[1] T. 3 N., R. 1 W., white kaolin occurs. In Section 7, T. 1 N., R. 2 W., yellow kaolin occurs three feet thick.

Martin County.

General Statement.—The Pennsylvanian system of rocks forms the subsurface of a large part of Martin County. The greater part of the county is occupied by the outcrop of the Mansfield sandstone, which contains iron ore which was formerly smelted at Shoals in this county. It was the mining of iron ore at the base of the Mansfield for the smelter at Shoals that led to the discovery of a large deposit of white kaolin in Lawrence County. In the eastern part of Martin County the streams have cut through the Mansfield and exposed the Chester shale, limestones and sandstones.

The Southern Indiana railroad crosses the northern part of Martin County from east to west and passes near the outcrops of kaolin. The B. & O. S. W. railroad crosses the county in an east and west direction, a little south of the center. A few outcrops of kaolin occur near this railroad in the eastern part of the county and just west of Shoals.

A brick plant which was erected at Shoals several years ago is not now in operation. The kaolin in this county is not being utilized at present.

The eastern third of Martin County is occupied by the attenuated border of the Pennsylvanian and exhibits its contact with the underlying Mississippian at many points. Although there are many outcrops of kaolin there has been little serious attempt at development.

Halbert Township.—In the southeast quarter of Section 16, where the public road ascends the divide between Beaver Creek and White River, is an exposure of mahogany clay which is several feet thick and underlies sandstones and shales of the Pennsylvanian. The clay contains some white streaks which resemble decomposed kaolin. Limestones of Mississippian age underlie the deposit. No attempt has been made at development. A similar outcrop occurs in the southeast quarter of Section 11, at the side of the public road. Sandstone overlies the mahogany clay at this point and shale underlies it. Several springs mark the line of contact of the

[1] Cox. 7th Annual Report Indiana Geological Survey, 1875, pp. 234-5.

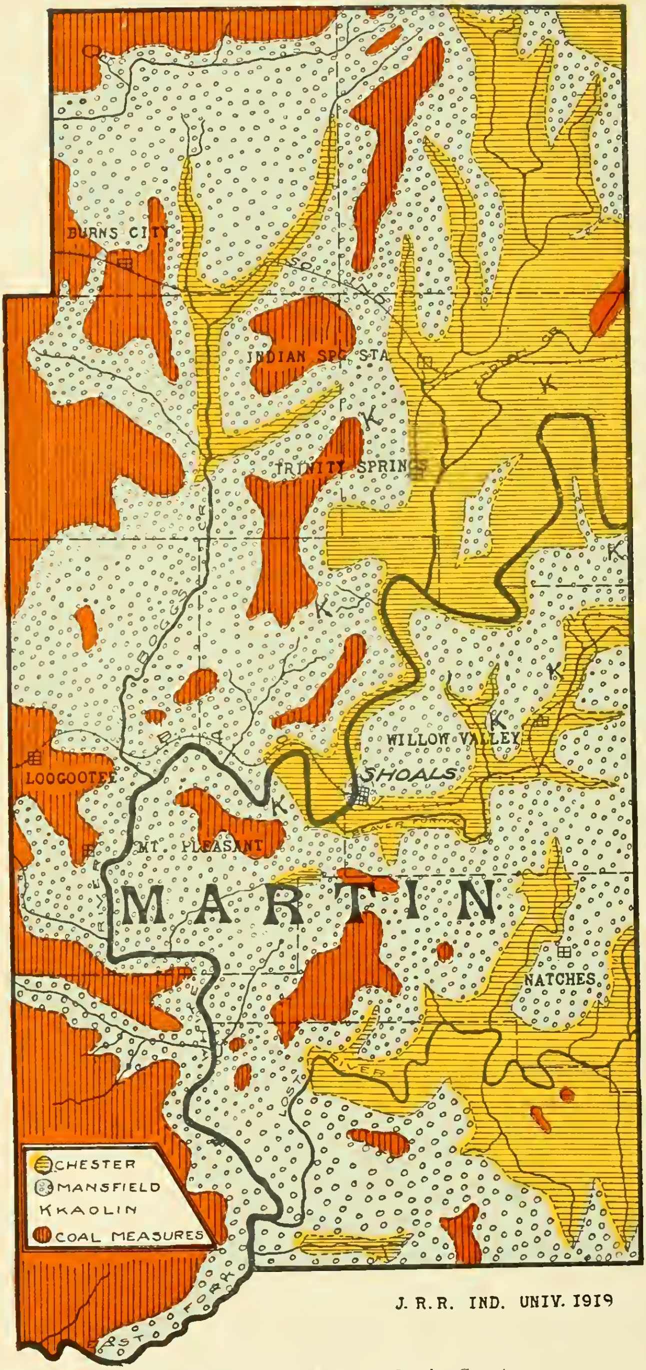

Plate XXXVIII. Map of Martin County.

sandstone and the shale. An outcrop of white kaolin was found many years ago at the base of a thick bed of sandstone in the northeast quarter of Section 12. It was reported to have been found in a well and below a spring in the southeast quarter of the same section.

West of the public road, in the southwest quarter of Section 2, many fragments of white kaolin were found on a slope which is covered with detritus from a slope which contains sandstone overlying shale. The sandstone is exposed at the top of the ridge and the shale in a small stream bed below the contact. The white fragments were very abundant around the holes made by groundhogs.

In the public road, in the northwest quarter of the same section, there is an outcrop of mahogany clay overlying a bed of bluish shale. Sandstone overlies the clay. The layers of sandstone are thick and the grains are well cemented with oxide of iron. An outcrop of mahogany clay occurs also in Section 1 in the public road near the center of the section. The underlying formation is shale and the overlying rock is sandstone.

Center Township.—In R. 4 W., T. 3 N., Section 1, kaolin occurs in the N. W. quarter. It underlies the Mansfield sandstone and rests on the shales of the Hardinsburg formation. The Glendean limestone which outcrops about 375 feet east of the Kaolin entry and the twenty feet of Tar Springs sandstone lying above underneath the Mansfield has been cut out by the Mansfield at this point. The Tar Springs sandstone at this point is composed of thin bedded sandstones, some layers of which are capable of being split into very thin laminæ. The thicker layers are suitable for the manufacture of whetstones. The kaolin consists of mahogany clay with fragments of white kaolin at the entrance, but it is said that back under the firm sandstone there is a five-foot layer of good white kaolin. This kaolin occurs on the edge of a basin which has been formed in the Chester rocks by pre-Pennsylvanian erosion.

In Section 2, near the southwest corner, there is an outcrop of mahogany clay which contains some small bands of white kaolin. The kaolin underlies the Mansfield sandstone and rests on the shales of the Hardinsburg. The elevation is about five feet lower than in Section 1.

Plate XXXIX. Reelsville limestone west of Huron. Brandy Run shale below and Elwren shale above. Contains much pyrite.

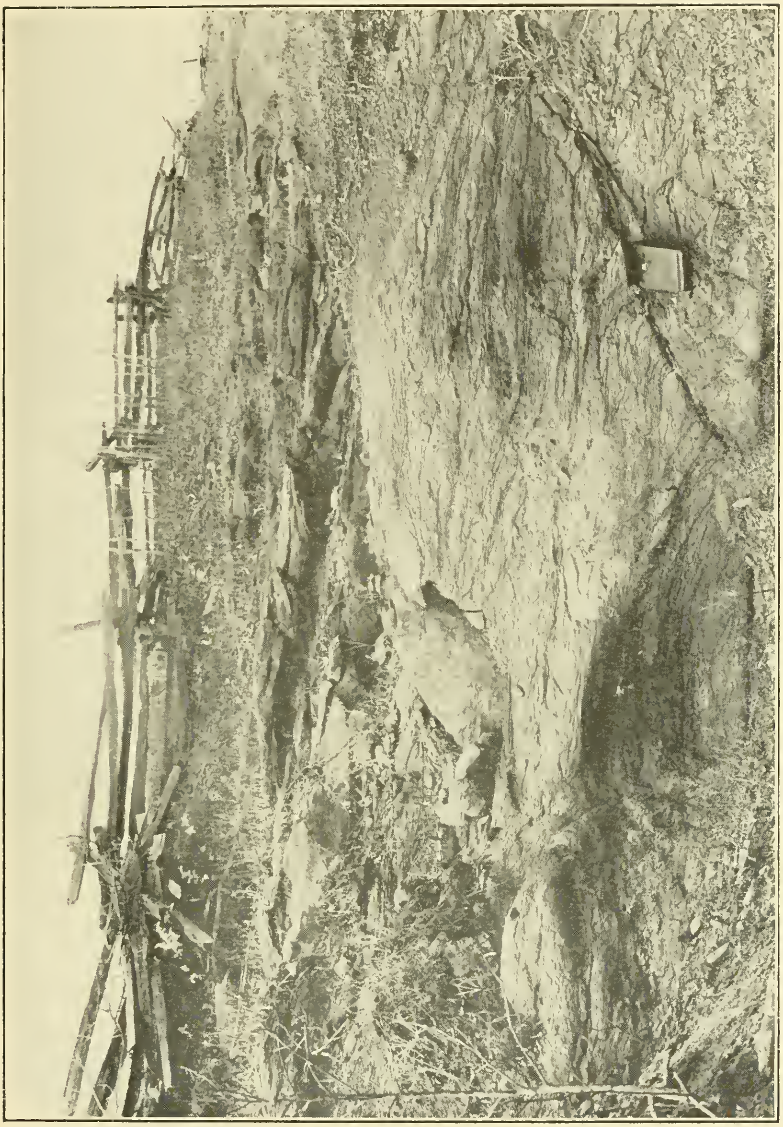

Plate XL. Outcrop of Elwren sandstone under which kaolin occurs in Monroe County. Fine of grain and cross-bedded.

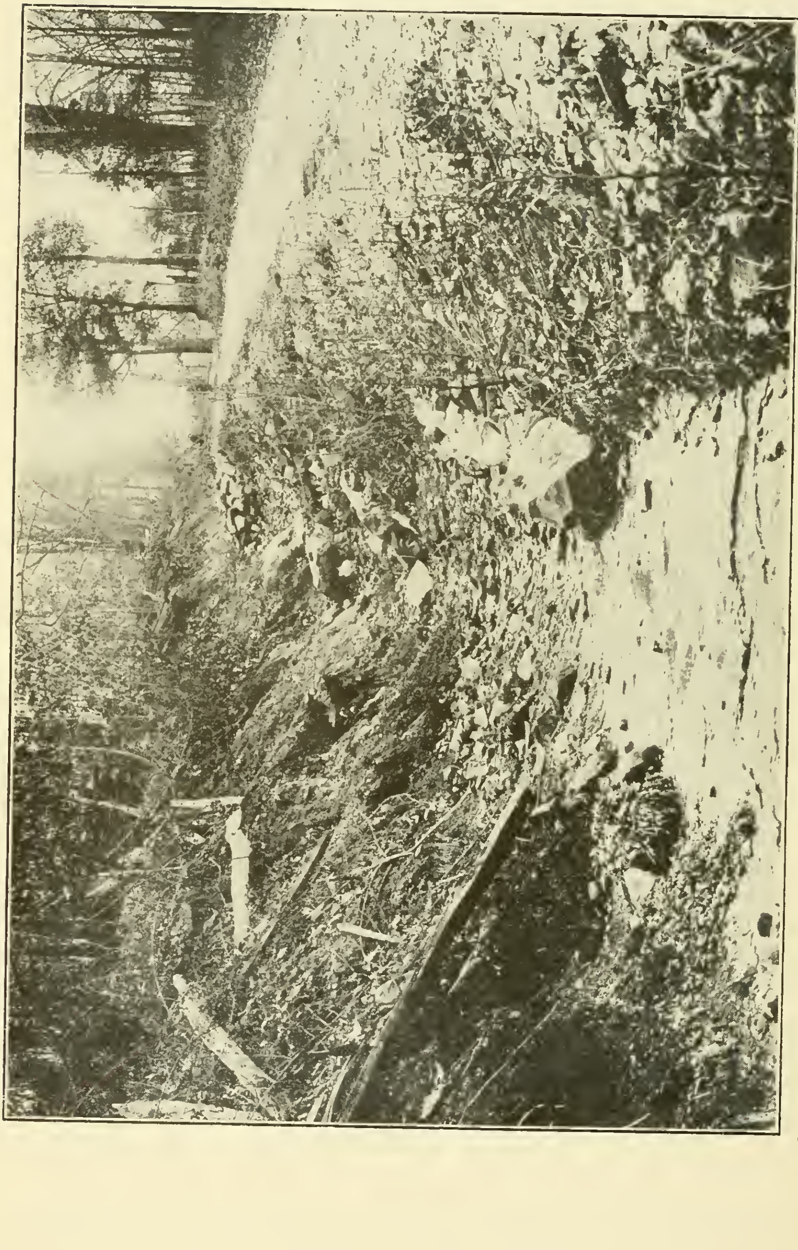

Plate XLI. Chester limestone and shale in Monroe County. Limestone where aneroid hangs surrounded by maroon clay.

In the northwest quarter of Section 27 kaolin occurs near the bank of White River in a small ravine which enters the river from the south. The Mansfield which occurs in the river bed at Shoals is forty feet above the river.

In Mitchell Tree Township, White River crosses the southeast corner of Section 1, producing a high bluff. The base of this bluff contains sixteen feet of Beech Creek limestone, overlying which is about twelve to eighteen inches of kaolin. Above the kaolin thin bedded Cypress sandstone having a thickness of five feet is succeeded by twenty-five feet of massive sandstone belonging to the Cypress. Above the Cypress is a high bluff of Mansfield sixty to seventy-five feet high. On top of the Mansfield are Lafayette gravels consisting of brownish colored gravels such as are found in the Knobstone and geodes such as occur near the Harrodsburg-Knobstone contact.

Along the high ridge between Indian Creek and White River several outcrops of kaolin occur below the Cypress sandstone. One of these occurs in Section 12 at an elevation of 695 feet above sea level.

An outcrop of white kaolin occurs in the public road in the southeast quarter of Section 16. A short tunnel has been dug into this deposit and considerable white kaolin occurs on the dump.

In Columbia Township, in Section 5, there is an outcrop of mahogany clay containing some fragments of white kaolin underlying the Mansfield.

Greene County.

General Statement.—The eastern part of Greene County lies within the outcrop of the Chester group of rocks, mainly, though, the Mansfield occupies a part of the region. The remainder of the county has its subsurface occupied by the rocks of the Pennsylvanian system. Outcrops of kaolin occur only in the eastern portion of this county and two railroads intersect it. The Monon branch from Bedford to Bloomfield crosses the southern portion and the Indianapolis branch of the Illinois Central crosses the northern portion.

The eastern part of Greene County lies within the driftless area. The exposures of the Pennsylvanian-Mississippian contact are numerous in the eastern tier of townships. The Mis-

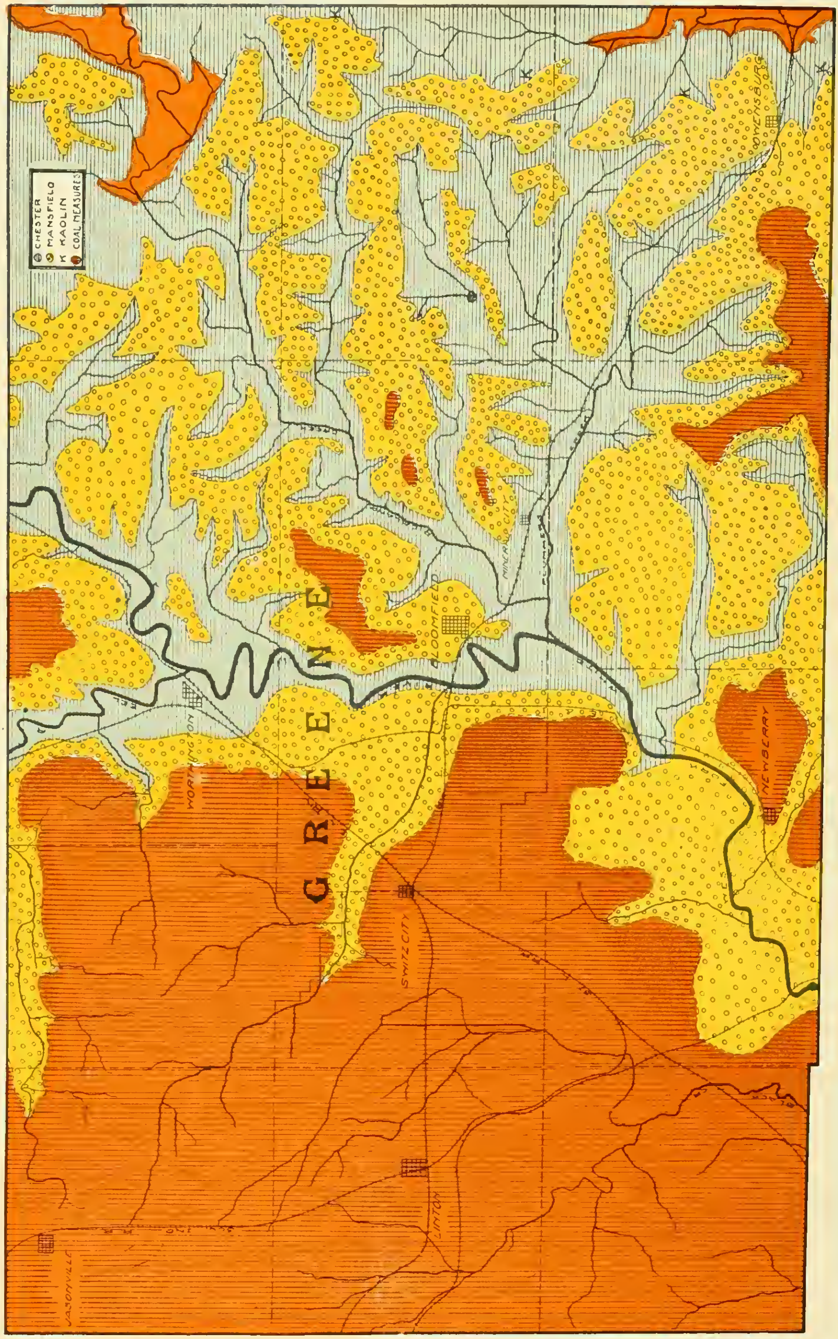

Plate XLII. Map of Greene County.

sissippian occupies the larger part of the surface, the Pennsylvanian forming irregular areas occupying the higher elevations. Mahogany clay has been found in Center and in Beech Creek townships. White kaolin is reported from the Sullivan, Coombz and Edwards places in these townships. In Center Township mahogany clay outcrops in Sections 1, 2, 10, 11, 12, 22 and 25.

Owen County.

General Statement.—That portion of Owen County adjacent to Monroe and southeast of White River is favorably located for the occurrence of kaolin so far as geological conditions are concerned. Both the Chester and Mansfield are represented by outcrops. Railroad facilities are not good in this part of the county, but the territory lies between the Illinois Central on the south and the Pennsylvania railroad on the north.

Specimens of the white kaolin were reported by Collett[10] from the headwaters of Raccoon and on Jordan and Rattlesnake creeks. Outcrops occur on the northwest quarter of Section 7, T. 9, R. 3, and in Sections 27, T. 11, R. 4.

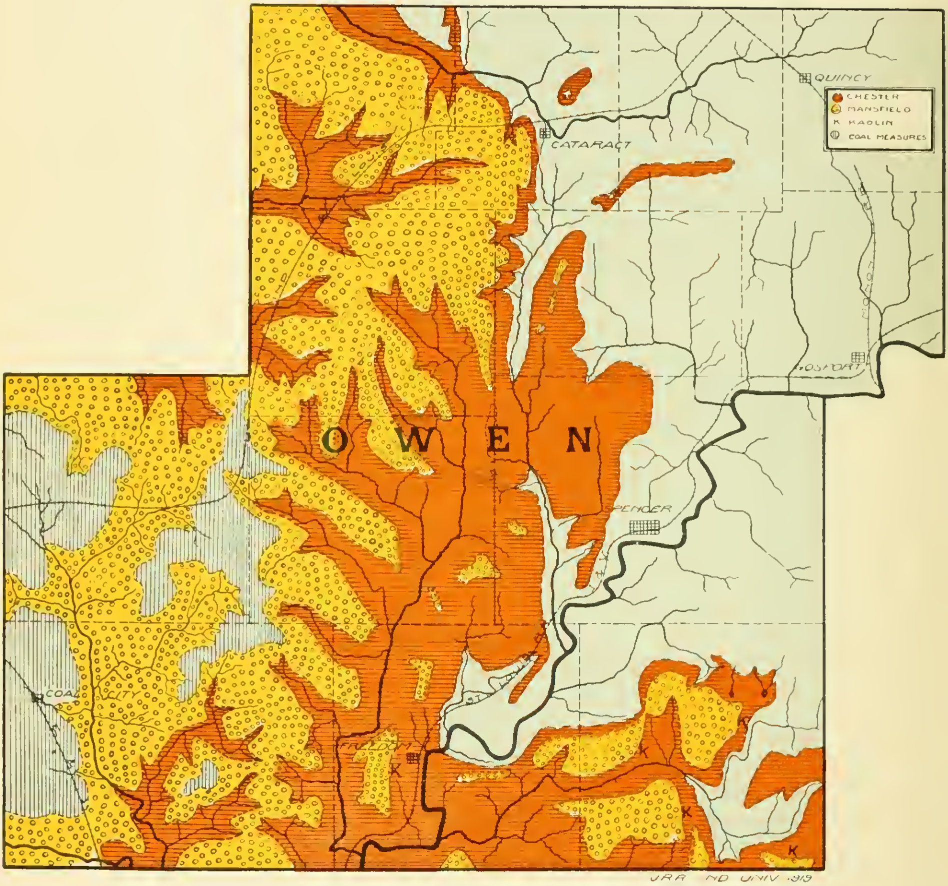

Plate XLIII. Map of Owen County.

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